EXPERIMENTAL VEGETATION

THE RELATION OF CLIMAXES TO CLIMATES

BY

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1. INTRODUCTION.

SCOPE AND PLAN.

The investigations that have led to the development of the phytometer and the experimental method in vegetation are companion efforts in the endeavor to organize ecology as a quantitative science. No subject has suffered more from the lack of training and experience or from the absence of basic procedure and adequate perspective. It has become obvious that this condition can be remedied and actual progress insured only by instrumental and experimental methods and by a combination of intensive and extensive studies that will check superficiality on the one hand and broaden limited horizons on the other. It is certain that much work of purely superficial or local character will continue to be done under the name of ecology, but the touchstones of instrument, quadrat, and experiment afford a ready means of eliminating such papers from consideration. No study deserves to be called ecological that does not deal with the cause-and-effect relation of habitat and organism in a quantitative and objective manner.

The task of focusing the efforts of the ecologist upon the habitat as cause and the plant and community as effect and reaction furnishes the theme for four related studies, namely, phytometers, experimental vegetation, climatic cycles, and changes of climate and climax. The first two constitute an endeavor to employ plant and community as the best measures of cause and reaction, while the last two emphasize the fundamental significance of change as the proper approach to this complex of problems.

PRINCIPLES.

The basic guides in this task are the cause-and-effect relation on the one hand and the cyclic nature of change on the other. The former is paramount in every ecological problem, since investigation that does not deal directly and constantly with causes lacks the very essence of science. However, in dealing with processes in a way that is at once complete and synthetic, ecology must not overlook the fact that both cause and effect must be inseparably associated and that effect sometimes affords the readier approach to the problem. It is equally essential that ecology be treated as inherently dynamic, that change in some degree or at some rate be regarded as universal, and that such changes be recognized as recurrent or cyclic, both as cause and in effect. The fact has elsewhere been emphasized that effects in turn produce reactions, which consequently become causal to the extent that they modify the original causes (Plant Succession, 79). This constitutes the basic cycle which finds its expression in the larger cycle of the sere. Thus, succession is an intrinsic function of all vegetation, though the shifting of climaxes is a matter of thousands or tens of thousands of years rather than of scores in the subsere or hundreds in the prisere.

The cyclic changes of the habitat are likewise reflected in the individual and the species. Adjustment and adaptation are clearly cyclic processes, and this is even more evident in the major evolutions of groups and floras. As the consequence of reaction and competition in the sere and of climatic shift in the major seres, invasion is necessarily cyclic and finds its typical expression in terms of dominant and relict phases. Finally, cyclic changes serve to link the present with the past in such a broadly continuous fashion that the gap between them disappears and such terms as ecology and paleo-ecology are seen to be mere conveniences.

METHODS.

The methods of experimental vegetation are based on the processes inherent in the natural development of vegetation, but segregated and controlled in such a way as to reveal the value and significance of each individual step or process. This is even true of migration, regarded merely as transport, the difference in the rôle of man as an unintentional or purposeful agent being immaterial, except as to the number and fate of the migrules. The most exact evidence as to the nature and success of invasion and ecesis is doubtless that to be obtained in the form of natural experiments, but except in the case of propagules these are difficult to discover outside of ecotones and are altogether absent from the typical areas of great associations. Hence, the only feasible procedure is to approximate the method of natural experiment as closely as possible, bearing in mind that the numbers must be large enough to insure against complete loss. Moreover, it must be recognized that artificial aids to ecesis, such as watering, screening, etc., fall well within the variation of factors in nature and are in consequence more or less natural.

The basic methods of experimental vegetation are as follows: (1) sowing seeds; (2) planting seeds or propagules; (3) planting seedlings; (4) transplanting adult plants of various ages; (5) transplanting small communities or portions of communities. The converse of this is to be found in the method of denuded quadrats and transects, but as this is primarily a question of ecesis within a community, it has not been extensively employed in the present study. The accessory methods involve the use or manipulation of (1) competition; (2) physical factors; (3) protection against animals; (4) instruments; (5) phytometers; (6) seasons and cycles. Time also enters the equation, inasmuch as germination and the ecesis of seedlings are periods of the greatest stress. Various ways are available for reducing or eliminating competition and modifying the physical factors, but the following have proved the simplest and most satisfactory, viz: (1) sowing on the surface in the midst of natural vegetation; (2) sowing or planting in trenches, by which competition is prevented for a short time; (3) sowing or planting in denuded quadrats, which eliminates competition for a much longer period, but renders the water relations usually less favorable at the same time that it improves light conditions; (4) transplanting adult plants into living cover or denuded areas, with similar consequences as to competition, water, and light; (5) improving the conditions for germination, establishment, or survival by watering, shading, thinning, draining, etc. A full battery of recording instruments is indispensable and must be supplemented by determinations of chresard, evaporation, and light intensity in all cases, and of salts and air-content whenever

these are controlling. Equally essential are phytometers of various types to serve as interpreters between the physical instruments and the natural cover on the one hand, and the transplants on the other. Furthermore, the differences between seasons and the wet and dry phases of the climatic cycle must be taken into definite consideration, as they are often greater than the climatic differences between the several grassland associations or even between formations. Finally, a clear distinction must be drawn between persistence and dominance, the former indicating the potential and the latter the actual rôle of a species in the climax.

VALUES.

The basic value of the experimental method in vegetation is evident, but its far-reaching significance warrants detailed consideration. While its first importance inheres in its being indispensable in the search for causes, the problems of the origin, unity, and relationship of formations and associations and their correlation with climate can be solved objectively and permanently in no other way. In fact, the objectivity afforded by comprehensive and repeated experiment is the paramount reason for its constant and universal use. The opinions and hypotheses arising from observation are often interesting and suggestive and may even have permanent value, but ecology can be built upon a lasting foundation solely by means of experiment. This does not mean that observation and reconnaissance have no value, but such results are to be regarded as provisional, pending adequate experimental study. Still less does it mean that hypothesis and theory are to have no part in an exact and quantitative ecology. Such a view is possible only to those who ignore the decisive rôle that theory has played in the development of modern chemistry and physics and are unfamiliar with its essential stimulus in the advance of biology.

The study of vegetation demands the use of experiment to even a greater degree than that of the plant, owing to the complexity and extent of the great communities and the consequent opportunity for making general observations and forming unchecked opinions. Moreover, it must be fully recognized that the intensive-extensive method of investigation applies with peculiar force to the plant community, since it was developed for the express purpose of turning complexity and extent to the advantage of thorough and detailed analysis. As a procedure, it has been fully justified by the experience of years in the vegetation of western North America, in which the extensive results of constant field studies have given perspective and balance as well as new points of departure to the results of the laboratory and station, and the latter have served to refine and definitize the natural experiments and observations over a vast territory.

THE GRASSLAND CLIMAX.

The development of the views as to the nature and structure of the grasslands of North America illustrates the need of objective methods of determining vegetation units and their relationships. This is all the more convincing, since the ecological investigation of the prairie and plains has been the work of a group with the same general training and outlook. In the first analysis of the grassland, Pound and Clements (1898:243, 1900:347) recognized two

prairie formations, viz, the prairie-grass and the buffalo-grass formations, a bunch-grass formation of the sandhills, and a meadow formation. In the light of successional studies, the last two are to be regarded as subclimaxes. In a few years (Clements, 1902) it had become clear that the prairie-grass or *Stipa-Agropyrum* formation and the buffalo-grass or *Bulbilis-Bouteloua* formation were the two great communities of the prairie-plains region. This was essentially the view also of Shantz (1906, 1911) and of Pool (1914). This conception was maintained in Plant Succession (180, cf. note) after many additional years of successional research. However, the developmental concept of the formation had broadened its scope and afforded a clearer view of its structure. As a consequence of the special study of these relations, it became necessary to abandon the view of two separate grassland formations and to recognize a single formation composed of several associations. Meanwhile, it had become increasingly evident that the *Agropyrum* consociation of the Northwest was closely related to the *Stipa-Agropyrum* prairie. This was first suggested by finding the three dominants associated from Washington to Montana during the field work of 1914, a view adopted by Weaver, who had worked intensively in this community (1917:40). This idea was confirmed by further studies in 1917, but the true relationship was obscure until it became certain in 1918 that *Stipa setigera* and *S. eminens* were the original bunch-grasses of California. As a consequence, it proved possible to recognize a fourth grassland association, composed of bunch-grasses and characteristic of the Pacific region of winter precipitation (Plant Indicators, 115). By means of extensive field work and the comparative study of communities, the actual relationship of the grassland units was determined, but the experimental method might well have accomplished in 5 years what observation required 20 years to attain.

TESTS OF UNITY.

In reaching the conclusion that the grasslands constitute a single climax formation and not several more or less related but distinct units, recourse was had to a number of tests, all as objective as possible.

"The conclusion that the grassland is a single great climax formation is based in the first place on the fact that the three most important dominants, *Stipa, Bouteloua,* and *Agropyrum,* extend over most of the area, and one or the other is present in practically every association of it. This would seem the most conclusive evidence possible, short of actual vegetation experiments, that the grassland is a climatic vegetation unit. Equally cogent is the fact that these dominants, together with *Carex, Bulbilis,* and *Koeleria,* mix and alternate in various groupings throughout the *Stipa-Bouteloua* association. Indeed, this association appears so conclusive as to the general formational equivalence of these seven dominants that it is regarded as the typical or base association. In addition, the characteristic societies either extend through several of the associations or are represented by corresponding communities belonging to the same genus. The relation of the associations to such subclimax species as *Andropogon scoparius, Calamovilfa longifolia, Aristida purpurea,* and *Elymus sitanion* further confirms the relationship of the dominants. The most obvious difference between the various associations is exhibited by the tall-grass prairies, *Stipa-Koeleria poium,* and the short-grass plains, *Bulbilis-Bouteloua poium.* Yet these are closely related, as shown not only by the criteria given above, but also by their geographical contact. Still more eloquent is the fact that grazing favors *Bouteloua* and *Bulbilis* at the expense of *Stipa* and *Agropyrum,* and thus frequently converts the

base association of *Stipa-Bouteloua* into a pure short-grass cover. Concrete evidence of this has been obtained in widely separated areas and has led to the working hypothesis that a pure short-grass community is partly if not largely a response to overgrazing." (Plant Indicators, 115.)

FURTHER EVIDENCE.

In the six years since the above was written, a large amount of additional evidence has been accumulated as to the unity of the grassland and the close phylogenetic relationship of its associations, quite apart from the experimental results brought forward later. In fact, the detailed field study of the ranges of the dominants makes it clear that the associations are even more closely related than was at first supposed, and the problem becomes one of maintaining several of these units as distinct rather than one of justifying their inclusion in the same formation. The number of dominants common to contiguous units has steadily increased, as well as the areas concerned. The most unique of the associations, the short-grass plains, has been shown to be a recent modification of mixed prairie due to overgrazing and has been more closely connected with the desert plains. The widespread dominants that occur in all the climatic associations have increased in number and now comprise *Stipa comata*, *Agropyrum glaucum*, *Bouteloua gracilis*, *B. racemosa*, *Sporobolus cryptandrus*, and *Koeleria cristata*.

Even more striking has been the evidence drawn from relicts and from seasonal variations arising out of the climatic cycle (Clements, 1921, 1922, 1923). These are the results of natural experiments on a scale and over an area that can not even be approximated by the experimenter, and their value is of the greatest, especially when supplemented by control experiments. In addition, the repetition and checking that are so indispensable are not only provided by recurrence in thousands of localities, but particularly also by the wide variation in behavior from season to season at the wet and dry phases of the climatic cycle. Of the first and the most direct importance are the relicts produced by overgrazing and by rodents, since these factors have operated directly upon the normal climax. Such relicts permit the complete reconstruction of the original community, both as to structure and extent. Indeed, this is usually done in the most graphic fashion by nature herself during seasons or phases of excessive rainfall, and when a drought period of several years is followed immediately by a year of exceptional rainfall, as happened from 1916–1919, a revealing picture is obtained. The expansion and contraction of relict areas at such a time reproduces in miniature what occurs during the wet and dry phase of a major climatic shift extending over a period of a thousand years or more. In the light of grazing relicts and cyclic changes it has proved possible to reconstruct all the grassland associations in detail as they were before the historical period in the West. Furthermore, reconstruction has been carried much farther back to a time probably 10,000 to 20,000 years ago, when the differentiation of the grassland mass into the various associations had barely begun. In short, the relict method confirms the view of the unity of the grassland climax by disclosing several stages in the differentiation of the original mass and affording a measure of the extent to which this has progressed. This is the theme of the volume on the changes of climate and grassland, and hence it will not be further elaborated here.

RELATIONSHIP OF THE ASSOCIATIONS.

The above suffices to indicate what appears to be clearly proven by the detailed evidence, namely, that the relationship of the six communities of the grassland is a phylogenetic one. This seems almost obvious in the case of the subclimax prairie and the short-grass plains. The latter is demonstrably a grazing subclimax of the mixed prairie, though such a hard-pan area as that about Burlington may be an actual relict of a short-grass climax developed during the last major dry phase. On the other hand, the subclimax prairie is just as clearly an eastward extension of the taller meadow-grasses from the true prairie, made in response to the same climatic shift and profiting by fire, especially during the prehistoric period. These changes are still so recent that the detailed steps can be readily followed, and similar adjustments can be traced between the other associstiona. However, the latter have been largely differentiated at an earlier period, and the phylogenetic and geographic connections are less broad.

The clue to the relationships of the four actual associations is to be found in the mixed prairie, which most nearly represents the original formation, and consequently affords a measure of the divergence of the others. The true prairie stands closest to the mixed prairie, *Agropyrum glaucum* and *Koeleria cristata* being common dominants, and the closely related *Stipa spartea* and *S. comata*, and *Sporobolus asper* and *S. cryptandrus* being reciprocal dominants in the two respectively. The chief difference lies in the fact that the short-grasses of the *Stipa-Bouteloua* association are usually absent, or form a fragmentary layer in the true prairie, except where grazing has favored their spread. The bunch-grass association resembles the true prairie in the absence of the short-grasses, but its endemic dominants are naturally different, e. g., *Agropyrum spicatum*, *Stipa setigera*, and *Festuca ovina* in place of *Stipa spartea* and *Sporobolus asper*. Its cognate relation to the mixed prairie is shown by such common dominants as *Stipa comata*, *Agropyrum glaucum*, and *Koeleria cristata*, and by the persistence to-day at the higher altitudes in the mixed prairie of such bunch-grasses as *Stipa setigera*, *S. eminens*, and *Festuca ovina*. The desert plains bear a close resemblance to the short-grass condition of the mixed prairie, the reduction of the upper layer of tall-grasses being more a matter of drought than of grazing. The close relationship of the two is shown by the dominance of *Bouteloua* in both, as well as by the fact that such tall-grasses as *Sporobolus cryptandrus*, *Bouteloua racemosa*, *Stipa pennata*, and *S. comata* persist as an upper layer in the desert plains wherever protection permits. Moreover, the relict areas in and about the Mohave Desert and Death Valley prove beyond doubt that the desert plains and bunch-grass associations were once in contact and that at an antecedent period they were commingled and probably identical (Clements, 1922, 1923).

CLIMATIC UNITY.

The fundamental fact in the relation of climaxes to climate is that this must be determined by plant judgments rather than by human ones (Plant Indicators, 116). This is necessarily truer of grasses than of trees, since their life-habits enable them to minimize or escape the rigors of winter as well as the dangers of the dry season of the year. Consequently, it should be regarded as neither strange nor perplexing to find such great grassland dominants as *Bouteloua gracilis*, *Stipa comata*, and *Koeleria cristata* ranging through a num-

ber of climates in the human sense. The human conception of a climate is loose enough at best, and it regularly ascribes much greater importance to temperature than to water relations. On the contrary, grasses are more responsive to differences of rainfall and evaporation than to those of temperature, *Bouteloua gracilis* in particular ranging much more extensively in latitude than in longitude as a climatic dominant. This is confirmed by the construction of dominance maps of the chief grasses, which disclose the fact that the interruption or disappearance of a consociation is primarily a matter of water, a conclusion entirely supported by the present investigation.

In addition, it must be recognized that obvious differences in the amount and distribution of rainfall may have slight significance for grasses. It is the amount and distribution during the growth period of the grass dominants that controls, and this is equally true of the effect of evaporation. The mixed prairie may range from 25 to 10 inches without undergoing any essential change in composition, owing to the fact that the period of development is shortened to fall within the limits of optimum water conditions. The existence of two rainy seasons, as in southern Arizona, seems to indicate an important difference in climate, but the growth of the grassland is still an effect of the much more adequate summer rains. The rainfall of the Pacific Coast is of the winter type and at first thought appears entirely different. However, this is only apparently true in so far as the native bunch-grasses are concerned. These bear the same general relation to the spring rains as that prevailing in the mixed prairie, namely, development begins during the rains, followed by maturity and the drying of the aerial parts in late spring or early summer respectively. The differentiating effect of the peculiar distribution of rainfall has been recorded in the characteristic life-form, though the progressive assumption of the bunch-grass habit is revealed by the fact that it is found in practically all the dominants of the desert plains and in nearly all the tall-grasses of the mixed prairie.

OBJECTIVES OF THE PRESENT INVESTIGATION.

As has been already indicated, the primary purpose of these researches is to develop an experimental method that will combine the maximum of demonstrability and objectivity. Because of its size and apparent complexity, vegetation affords an open field for prepossession and interpretation, and its study can be made scientific in the proper degree only by the resolute employment of experiment and measurement. The special ends of this investigation are many, chief among which are the demonstration of the unity of the grassland climax and climate, and the growing differentiation of the associations, partly in response to the subclimates and partly to the changes wrought directly or indirectly by man. It has also proved possible to cast further light upon the relationship of climatic and edaphic areas in the same region, as well as upon the significant rôle of climatic cycles and community shiftings in this. A special endeavor has been made to analyze competition in minuter detail and to evaluate more fully the effect of light intensity in a grassland cover. Particular attention has been directed to germination, seasonal ecesis, and final survival, especially in relation to annual variations in climate. Finally, the entire study has been designed to exemplify a new aspect of the phytometer method, in which native species and communities have received the major emphasis.

STATIONS.

Location.

The stations were chosen to represent typical conditions in each of the four grassland communities occurring in the vast area between the Missouri River and the Rocky Mountains. Lincoln, Nebraska, was selected as representative of true-prairie conditions. Aside from the matter of convenience in the use of the facilities of the Department of Botany of the University of Nebraska, the vegetation and environment of this region are better known than anywhere else in the grassland formation, due especially to continued study by Pound and Clements (1897, 1898, 1900), Clements (1905, 1907, 1916, 1920), Pool (1914), Weaver (1917, 1919, 1920, 1921, 1922, 1923), and others. Phillipsburg, in north-central Kansas, was selected as representative of mixed-prairie conditions, while Burlington, in eastern Colorado, was chosen in the short-grass plains. Phillipsburg lies about 190 miles southwest of Lincoln, and Burlington about 180 miles further west and south, 10 miles

Fig. 1.—Map showing location of stations in the four grassland communities.

west of the Kansas-Colorado State line (fig. 1). The altitude at the several stations rises from 1,100 feet at Lincoln to 1,900 feet at Phillipsburg and 4,160 feet at Burlington. Precipitation, the chief factor in determining the type of vegetation, ranges from 28 to 23 and 17 inches at the respective stations, decreasing westward. A fourth station was maintained at Nebraska City, Nebraska, about 50 miles southeast of Lincoln, near the Missouri River. Although the rainfall of 33 inches is sufficiently ample to produce scrubland or woodland, except for grazing, mowing, fires, etc., this station lies just within the border of the subclimax grassland and was chosen largely because of its ready accessibility.

In addition to the four stations mentioned, considerable experimental work was carried on at the mixed-prairie station at the foot of Pike's Peak near Colorado Springs, the Alpine Laboratory being used as a base. At Lincoln

a whole series of stations, ranging through gravel-knoll, high prairie, low prairie, salt-flat, swamp, and cultivated fields, was maintained. Moreover, reciprocal transplants from Tucson, Arizona, and Berkeley, California, have been made at many of the stations.

True-prairie Stations.

The high-prairie station at Lincoln (plate 1) was located on a rather flat hilltop about 60 feet above the general level of the flood-plain of Salt Creek and 2 miles north of the city. The fertile soil is of the type commonly called loess, but is really a glacial drift. It is a silt-loam belonging to the Marshall series, with a moisture equivalent of about 28 per cent and a maximum water capacity of approximately 60 per cent. The mechanical and chemical analyses of soils taken from an adjacent field in the same area (Weaver, 1920:140) indicate its general characteristics (tables 1 and 2).

Table 1—*Mechanical analysis of high-prairie soil.*

Depth of sample.	Coarse gravel.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
0.0 to 0.5 foot	0.0	0.0	2.0	1.9	6.0	26.1	39.3	24.7
0.5 to 1.0 foot	0.0	0.0	1.2	2.2	3.8	21.8	38.4	32.6
1 to 2 feet	0.0	0.0	2.7	2.9	4.8	19.6	45.6	24.4
2 to 3 feet	0.0	0.0	5.6	6.9	10.1	23.1	32.8	21.5
3 to 4 feet	0.0	0.0	7.0	8.8	12.8	23.5	28.3	19.6

Table 2.—*Chemical analysis of high-prairie soil.*
[Digestion with HCL (sp. gr. 1.115) for 120 hours.]

Depth of sample.	Insoluble residue.	Soluble salts.	Volatile matter.	Iron and aluminium oxid.	Calcium oxid.	Magnesium oxid.	Phosphorus pentoxid.	Nitrogen.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
0.0 to 0.5 foot	76.87	17.12	6.01	13.20	0.68	1.19	0.13	0.159
0.5 to 1 foot	75.70	18.58	5.72	14.25	.70	1.32	.12	.134
1 to 2 feet	76.17	19.08	4.75	14.72	.75	1.68	.12	.079
2 to 3 feet	77.80	18.46	3.68	14.03	.86	1.69	.15	.045

The soil is fine in texture, being composed mostly of silt and clay, and is sufficiently supplied with calcium to lack acidity. Determinations throughout a number of years show that the subsoil is usually moist to great depths, although at infrequent intervals during drought periods the holard may be reduced below the wilting-coefficient of Briggs and Shantz (1912) to depths of 4 to 5 feet, leaving only a small chresard for vegetation. Root excavations and bisects show that the plants are not only rooted deeply, but also that the root-systems of different species form layers in the soil, the shallowest one ending at about 3 feet and an intermediate one at 5 feet, while a third layer extends far below this level (Weaver, 1920:28, 40).

The vegetation is distinctly of the tall-grass sod type. *Andropogon scoparius*, *Stipa spartea*, *Koeleria cristata*, and *Bouteloua racemosa* are the chief grasses, although *Andropogon furcatus* and *nutans* occur more or less along with *Poa pratensis*. The interstitial *Panicum scribnerianum* and the relict *Bouteloua gracilis* are of much less importance. Prevernal societies are represented by *Antennaria campestris* and *Carex pennsylvanica*. Such vernal bloomers as *Astragalus crassicarpus*, *Baptisia bracteata*, *Senecio plattensis*, and *Nothocalais cuspidata* are abundant, while the variety and abundance of estival herbs indicate favorable growth conditions throughout the early summer. Chief among these are *Psoralea floribunda*, *Erigeron ramosus*, *Brauneria pallida*, *Meriolix serrulata*, and *Achillea millefolium*, although a host of others occur (Pound and Clements, 1900; Weaver and Thiel, 1917). Species of *Solidago*, *Aster*, *Liatris*, *Helianthus*, *Kuhnia*, etc., constitute the most important autumnal societies, the subdominants during summer and autumn giving a truly kaleidoscopic appearance. An average grass-level of 6 to 8 inches and an upper story of forbs at 15 to 22 inches is attained by June 1, although the flowerstalks of *Stipa* and the later grasses and herbs are 2.5 to 3.5 feet tall (plate 1).

Mixed-prairie Station.

This occupies an area just south of Phillipsburg, quite typical of the gently rolling topography, on a hillside which slopes gently southward (plate 2A). The fertile soil is a mellow, dark-brown, very fine sandy loam of the Colby series. At a depth of 12 to 15 inches it is slightly lighter in color and contains enough clay to be quite sticky, although when wet it is dark in color to a depth of 2 feet. Below this level it is light yellow and shows its loess origin throughout. The first 4 feet have a water-holding capacity of about 66 per cent. As is true of most soils of semiarid regions, it shows no acidity at any depth, and the mellow subsoil is very deep.

Table 3.—*Mechanical analysis of soil at Phillipsburg, Kansas.*

Depth of sample.	Coarse gravel.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
0.0 to 0.5 foot	0.0	0.0	0.3	0.2	1.2	43.5	35.8	19.0
0.5 to 1 foot	0.0	0.0	0.0	0.2	0.5	44.4	32.8	22.1
1 to 2 feet	0.0	0.0	0.0	0.2	0.3	39.7	34.0	25.8
2 to 3 feet	0.0	0.0	0.0	0.3	0.6	41.2	31.9	26.0
3 to 4 feet	0.0	0.0	0.0	0.1	0.2	37.5	31.4	30.8

Repeated excavations for the examination of the roots of native and crop plants from 1919 to 1921 showed that the soil was moist to 8 feet. This condition is assumed to be abnormal for the region, but it is directly to be correlated with the excessive precipitation of 1919 (Weaver, Jean, and Crist, 1922:77). However, this station is somewhat subject to drought, the holard to a depth of 4 feet being sometimes reduced approximately to the hygroscopic coefficient, about 10.6 per cent. Under these conditions the native vegetation is rooted almost or quite as deeply as in the true prairie (Weaver, 1920:93). The vegetation is essentially mixed prairie, the tall-grasses alternating with

or forming a layer above the short ones (plate 2A). *Andropogon scoparius, nutans,* and *furcatus* often form more or less continuous irregular sods varying from 6 inches to 7 feet in diameter, from which short-grasses may be almost entirely excluded, while *Agropyrum glaucum* likewise frequently occupies large areas rather exclusively. *Bouteloua racemosa* and *Elymus canadensis* are other important tall-grasses. Alternating with these are similar or on drier slopes even larger areas of *Bulbilis dactyloides* and *Bouteloua gracilis,* the intervals being nearly devoid of vegetation, often to the extent of one-fourth of the surface. More usually, however, the two kinds of grasses are intimately mixed, the short-grasses often showing a strong tendency toward the bunch habit. *Carex filifolia* and *stenophylla* supplement the understory of grasses, the leaves of which reach an average height of about 4 inches (before flower-stalk production), as contrasted with the midsummer tall-grass level 4 to 10 inches above. A taller open layer of *Psoralea tenuiflora* at 2 feet characterizes much of the area in late June, when societies of *Ratibida columnaris* and *Morongia uncinata* are also conspicuous. However, as emphasized by Clements (1920:138), the mixed prairie shows its xerophytic tendency by less numerous and less extensive societies. *Antennaria campestris, Astragalus crassicarpus, Nothocalais cuspidata, Anemone caroliniana, Senecio plattensis, Vicia americana,* etc., are all represented, even if sparingly, in the spring and early summer, but the absence of *Viola, Stipa, Koeleria,* and *Brauneria* is at once noted, and the presence of *Astragalus mollissimus, Oxytropis lamberti, Malvastrum coccineum, Opuntia fragilis, O. camanchica, Aristida purpurea,* and *Plantago purshi* indicates a more xerophytic type of vegetation. The subdominants of midsummer are usually smaller and less abundant than eastward, while the autumnal aspect likewise lacks many species common to the true prairies. The part of the mixed prairie used for experimental planting was carefully selected with due regard to a proper balance between tall and short grasses.

Plains Station.

This is located just north of Burlington, on a vast level tract (plate 2B). The soil is a rich, brown, fine sandy loam, very compact and hard when dry. It has a water-holding capacity of 65 to 70 per cent to a depth of 4 feet. At a depth of 2 to 2.5 feet it is underlaid with a so-called hard-pan. Soil analyses show that the concentration of colloidal clay and carbonates in the subsoil is sufficient to give rise to a hard-pan, i. e., a much more compact intercalated stratum of soil, upon its becoming completely dried out (Weaver and Crist, 1922). Silt constitutes about one-third of the soil at all depths, while the sand decreases and the clay increases in amount to 4 feet (table 4).

Table 4.—*Mechanical analysis of soil at Burlington, Colorado.*

Depth of sample.	Coarse gravel.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.	Hygroscopic coefficient.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
0.0 to 0.5 foot..	0.0	0.0	0.0	0.1	2.6	48.6	33.4	15.3	10.9
0.5 to 1.0 foot..	0.0	0.0	0.0	0.1	2.2	49.1	32.5	16.1	10.9
1 to 2 feet.....	0.0	0.0	0.0	0.2	1.9	46.7	32.0	19.3	12.2
2 to 3 feet.....	0.0	0.0	0.0	0.1	1.5	45.5	31.0	21.9	12.0
3 to 4 feet.....	0.0	0.0	0.0	0.1	0.9	42.2	34.2	22.6	11.4

Chemical analyses show that carbonates are practically absent in the surface soil, but increase rapidly with depth, and often reach concentrations of 5 or 6 per cent in the hardpan layer, which appears somewhat chalky in color. The soil is not at all acid; the carbon dioxid increases very rapidly with depth and is high at 2 to 4 feet. This soil is rich in phosphorus and potassium and has a sufficient supply of nitrogen, and hence all the essential raw materials are present in abundance.

TABLE 5.—*Chemical analysis*[1] *of soil at Burlington, Colorado.*

Depth of sample.	Acidity.	Carbon dioxid.	Volatile matter.	Phosphorus pentoxid.	Sulphur trioxid.	Potassium oxid.	Nitrogen.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*	*p. ct.*
0.0 to 0.5 foot..	None.	0.03	4.67	0.189	0.007	2.32	0.184
0.5 to 1.0 foot..	None.	0.30	3.13	0.504	0.017	2.39	0.130
1 to 2 feet.....	None.	1.71	3.11	0.428	0.006	2.45	0.101
2 to 3 feet.....	None.	2.10	3.34	0.406	0.006	2.51	0.086
3 to 4 feet.....	None.	2.60	2.84	0.525	0.005	2.22	0.084

[1] Phosphorus determinations were made by digestion with HNO_3 and HF, sulphur by fusion with Na_2O_2, potassium by fusion with calcium carbonate, and nitrogen by the modified Gunning method.

Water penetrates very slowly and run-off is usually high in this fine-textured soil. Shantz (1911) has shown that the average run-off from the short-grass sod at five stations in this region was 37 per cent of the total rainfall, while the maximum run-off reached 55 per cent. Consequently, the actual precipitation of 17 inches is a poor index of the efficiency of the rainfall. After heavy rains, 3 days were required for water to penetrate to a depth greater than 6 inches. The excellent root development of native plants in the surface 1.5 to 2.5 feet of soil enables them to absorb water readily, and further prevents a deeper penetration of rain. Determinations of the holard through a series of years (1920 to 1923) show that the soil is seldom moist below 2 feet, while by midsummer the amount above this level is frequently reduced to the hygroscopic coefficient. When this happens, the short-grass cover dries out and "cures" on the ground.

Closed mats of *Bulbilis dactyloides*, usually mixed with *Bouteloua gracilis*, make up fully 90 per cent of the vegetation, forming a carpet seldom over inches deep, exclusive of the flower-stalks (plate 2B). *Agropyrum glaucum* is frequently associated with the short-grasses, but overgrazing and drought have resulted in a dwarf habit and it forms flower-stalks sparingly, except in years of more than normal rainfall. These grasses, with their widely spreading roots, occupy the soil so thoroughly that relatively few important subdominants are present. Most conspicuous among these, and increasing in abundance where overgrazing has occurred, are *Aristida purpurea*, *Opuntia camanchica*, *O. fragilis*, *O. polyacantha*, *Festuca octoflora*, *Plantago purshi*, and *Schedonnardus paniculatus*. *Erysimum asperum* and *Psoralea tenuiflora* also are often abundant, while small, poorly developed societies of *Astragalus crassicarpus*, *Malvastrum coccineum*, and *Ratibida columnaris* are infrequent. Decreased size, vigor, and number are characteristic of most of the species when compared with their growth in more favorable conditions.

While some of the species of the meager flora are rooted entirely in the surface soil, others reach depths of 4 feet or more, especially the dominant grasses and the legumes. However, even these are relatively shallow when compared with the great depth attained by species in the moist subsoil of the true prairie.

PHYSICAL FACTORS.

Rainfall and Holard.

The grassland associations concerned lie in the region of summer rainfall; by far the greater part of the rain falls during the growing-season and only about one-tenth during the three winter months (fig. 2). Such a seasonal distribution of the precipitation is very favorable to the growth of grasses. The normal decrease of 5 inches at Phillipsburg in comparison with Lincoln and the further decrease of 6 inches at Burlington are quite evenly distributed through the season. Moreover, the type of rainfall is similar throughout, consisting usually of heavy showers, often of rather short duration, though this is more marked upon the high plains than eastward, where the rains are more general. At all stations it results in much run-off, but this is particularly heavy on the compact soil at Burlington. However, in the plains region more of the precipitation falls in light showers of 0.2 inch or less, which are of practically no value in increasing the holard. At each station the holard has in general been very similar at any particular time during the three seasons (1920 to 1922), and the comparison of a single season's data will suffice here (table 6).

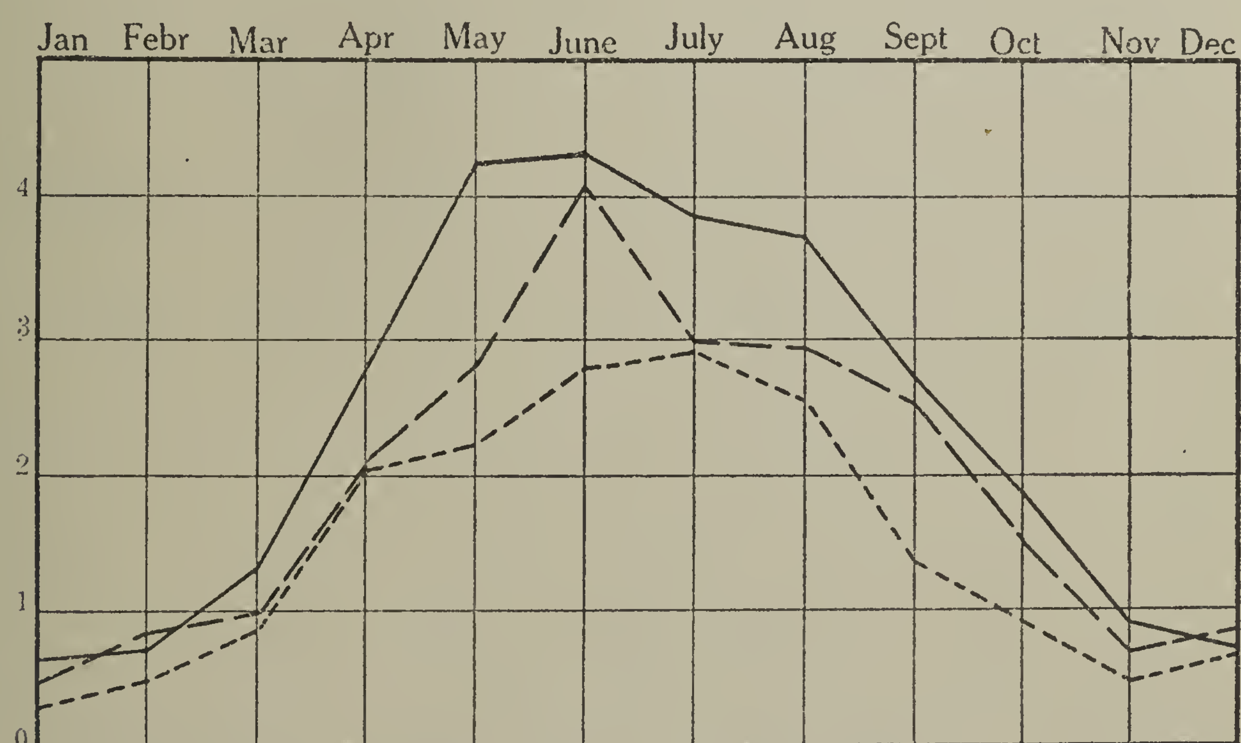

Fig. 2.—Mean annual precipitation at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines).

At Lincoln a sufficient amount of water to promote good growth was available at all depths and at all times. At the mixed-prairie station, July and early August were periods of drought and at times of actual deficiency. The holard at Burlington was favorable until June, but after this time marked deficiencies were of frequent occurrence. However, the value of water-content to the plant is not determined entirely by its quantity, but largely also by the

Table 6.—*Holard in excess of the hygroscopic coefficient at the several stations, 1920.*

Lincoln, Nebraska.

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 10	17.6	16.1	14.1	10.0	8.6
Apr. 21	17.5	22.4	20.3	....	....
May 5	20.5	19.1	19.7	....	....
June 9	18.7	20.3	....	....	....
June 16	5.9	12.5	14.8	15.6	....
June 23	4.9	7.1	9.6	....	....
July 14	22.0	16.8	9.1	13.2	14.7
July 28	7.2	3.9	6.3	....	....
Aug. 5	2.5	4.0	5.4	9.7	11.6
Aug. 12	8.7	5.7	4.8	....	....
Aug. 19	26.3	7.7	3.2	....	....
Aug. 31	Continued heavy rains; no samples taken.				
Wilting coef	14.0	12.9	12.6	10.5	9.1
Hygroscopic coef	9.5	8.7	8.6	7.1	6.2

Phillipsburg, Kansas.

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
May 7	14.7	15.3	12.5	14.7	14.0
June 2	4.8	6.6	11.6	11.8	13.0
June 10	7.6	9.7	9.0	....	....
June 24	6.6	3.1	5.0	9.0	....
July 1	1.9	4.1	2.8	....	....
July 9	1.5	2.8	1.6	....	....
July 21	−1.4	0.1	−0.2	2.3	5.3
Aug. 4	0.7	7.7	−0.3	0.5	3.5
Aug. 18	12.6	12.3	5.4	....	....
Aug. 26	4.0	4.1	0.4	2.0	5.5
Wilting coef	13.3	13.3	13.4	13.5	13.1
Hygroscopic coef	10.6	10.6	10.9	10.6	10.7

Burlington, Colorado.

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 15	16.7	13.7	11.1	4.9	1.8
June 3	2.3	5.2	7.3	6.9	2.9
June 12	−1.8	−0.1	2.8	....	....
June 25	7.4	2.5	1.8	1.4	−2.5
July 2	−1.6	−0.5	0.0	....	....
July 8	−2.9	−1.3	−2.2	....	....
July 20	−0.7	−2.7	−1.7	2.5	−0.6
Aug. 5	4.6	2.7	−2.7	−0.6	−3.1
Aug. 19	−3.1	−3.1	−0.5	....	....
Aug. 24	−0.8	−2.1	−1.9	−0.6	−1.4
Wilting coef	13.3	13.3	14.0	14.5	14.0
Hygroscopic coef	10.9	10.9	12.2	12.0	11.4

rate of loss both through the plant and by surface evaporation. These in turn are controlled by humidity as affected by temperature, wind, etc., all of which are more or less integrated in the evaporation.

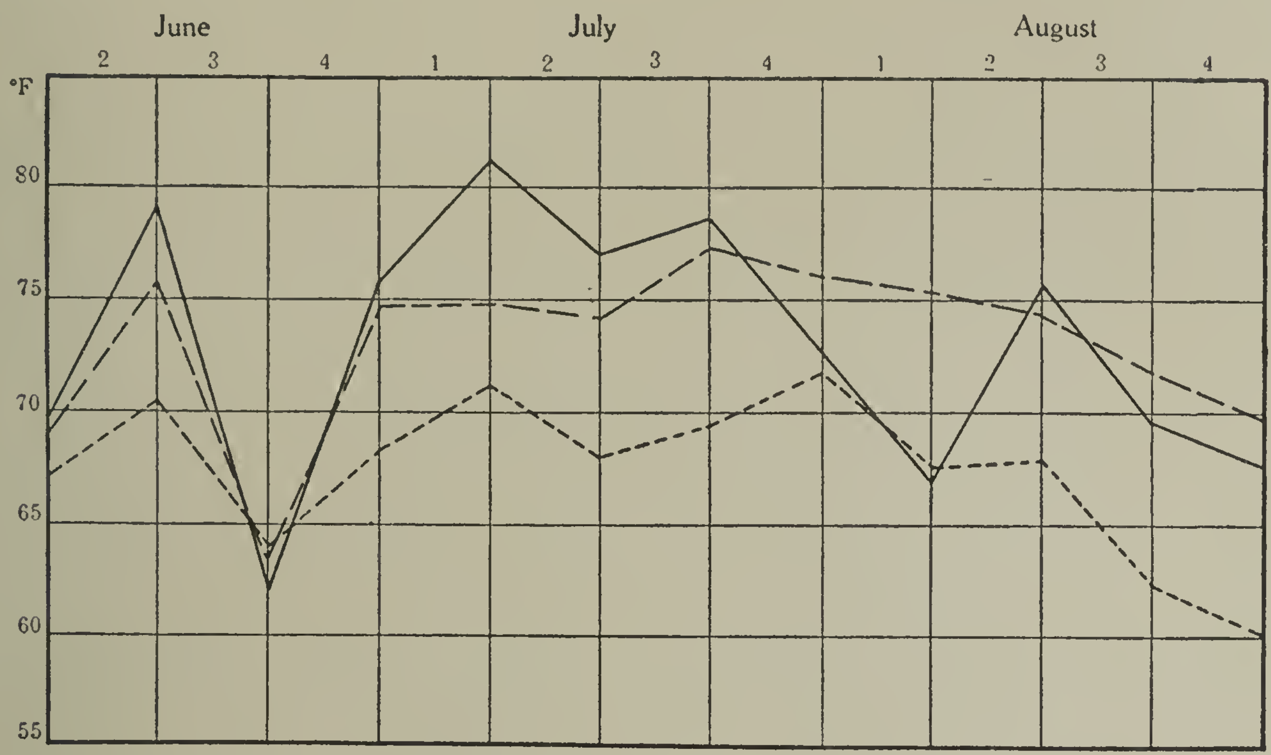

FIG. 3.—Average daily temperature at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1920; here, as elsewhere, the numbers denote the first, second, third, or fourth week in the month, respectively.

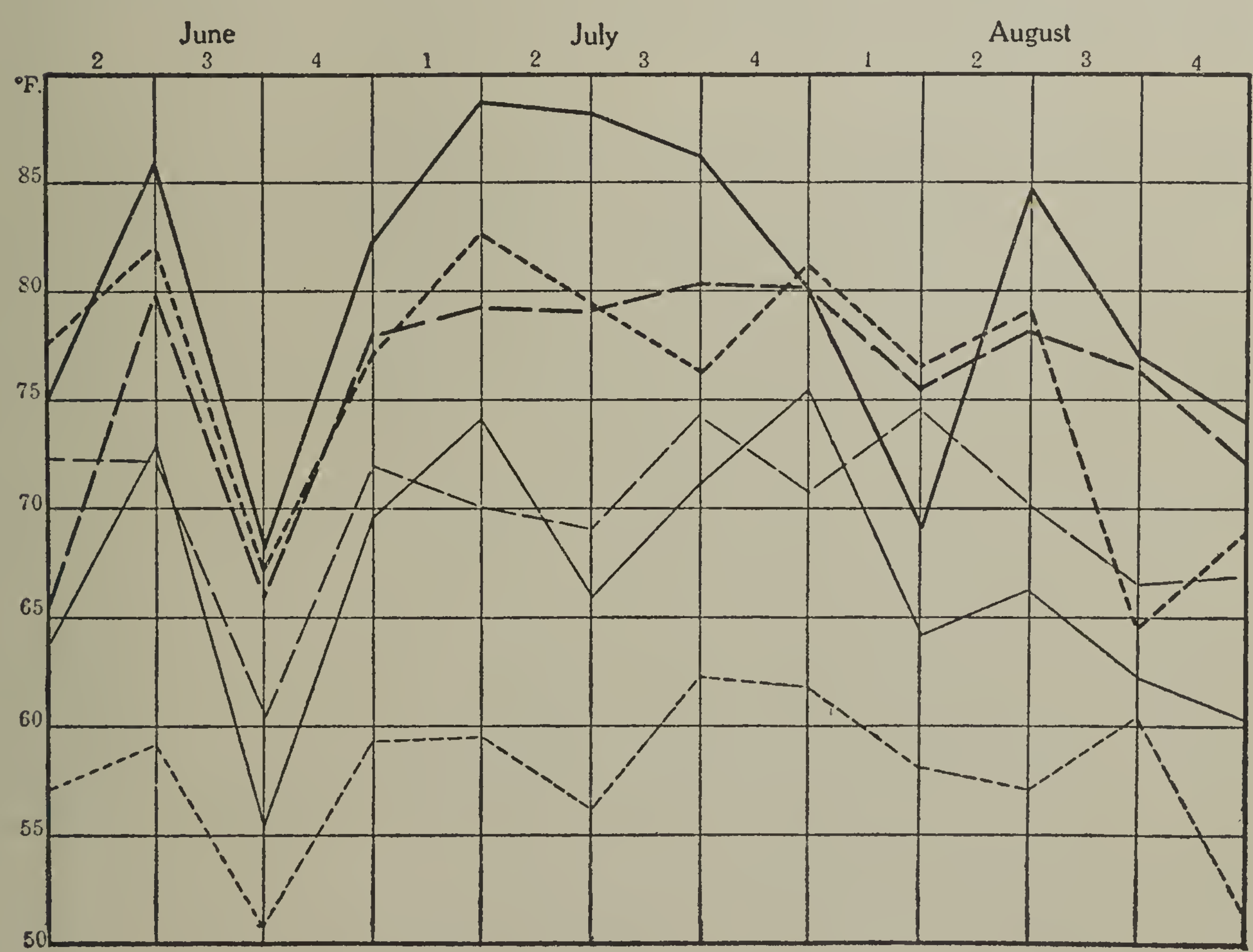

FIG. 4.—Average day (heavy lines) and night (light lines) temperatures, at Lincoln (solid lines), Phillipsburg (long broken lines), and Burlington (short broken lines), 1920.

TEMPERATURE.

Because of differences in elevation, which more than offset those of latitude, spring usually opens about 7 to 10 days later at Phillipsburg, and 18 to 23

days later at Burlington, than at Lincoln. These stations are 800 and 3,000 feet higher respectively than Lincoln. Air temperature was usually 5° to 7° less at Burlington than at Phillipsburg, and also lower at the latter than at Lincoln. Likewise, the average day temperatures were highest at Lincoln and lowest at Burlington, and this same general relation held for average night temperatures (figs. 3 and 4). The night temperatures at Burlington varied from 45° to 67° F. These were more or less unfavorable to growth, but their chief effect was probably through humidity, differences of temperatures as such probably having little effect upon the type of grassland.

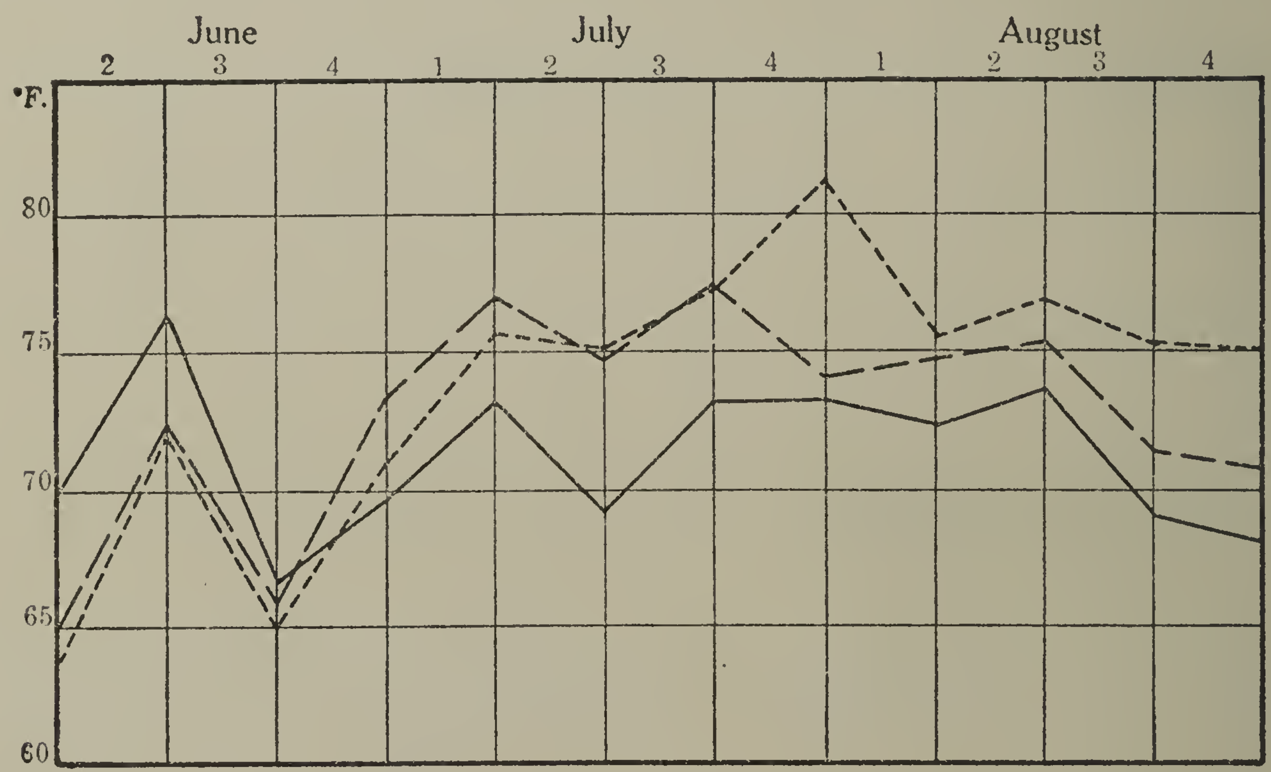

Fig. 5.—Average daily soil-temperatures at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1920.

Soil temperatures were highest at Lincoln (70° to 77° F.) and lowest at Burlington (64° to 72° F.) during the first half of June, but by the last week this relation was reversed, the soil at Burlington remaining warmest throughout the season (fig. 5). The average weekly differences were often as great as 6° to 8° F., the soil at Lincoln being coldest, at Phillipsburg intermediate, and the dry soils at Burlington having the highest temperatures.

The much greater daily range of both temperature and humidity at the Burlington station as compared with that at Lincoln is shown in figure 6, and the average day and night humidities for 1920 are given in figure 7. Conditions at Phillipsburg were more or less intermediate. This combination of high temperature and low humidity, which occurs rather regularly in the afternoons at Burlington, when coupled with dry soil, obviously promotes transpiration and depresses growth.

Wind and Evaporation.

The wind movement is much greater at Burlington than at either of the other stations and is an important factor in desiccating both plants and soil. An average day velocity of 8 or 10 miles per hour at a height of 0.5 meter is quite usual, while periods of several days with a velocity of 20 to 30 miles per hour are not uncommon. The amount of wind is less at Phillipsburg and much less at Lincoln (for example, a daily average of 4 miles per hour from

July 13 to September 19, 1916). The evaporation, which in a measure integrates the factors of radiant energy, humidity, and wind movement (fig. 8), was greatest throughout the season of 1920 (23 to 60 c. c. average daily evaporation from white cylindrical non-absorbing atmometers) at Burlington,

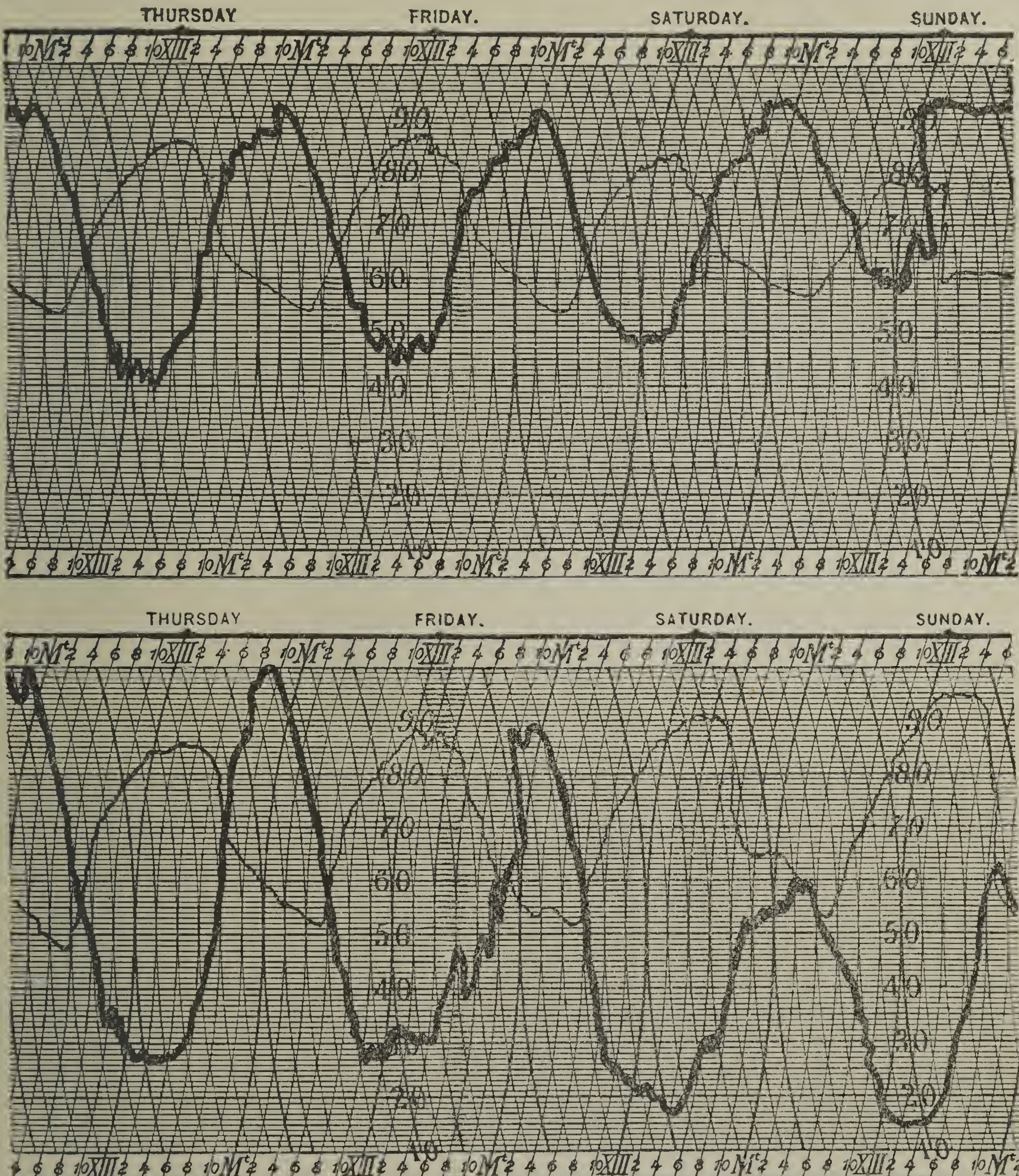

Fig. 6.—Hygrothermograph records from Lincoln (upper) and Burlington (lower), June 1921; light lines temperature, heavy lines humidity.

intermediate at Phillipsburg (11 to 32 c. c.), and least at Lincoln (9 to 25 c. c.). Similar constant differences of evaporation rates were obtained the following seasons.

In consequence, the conditions for plant-growth as regards rainfall, holard, temperature, humidity, wind, and evaporation are normally most favorable at Lincoln, intermediate at Phillipsburg, and least favorable at Burlington. These conditions are indicated by the native vegetation and borne out by the growth of crop plants (Weaver, Jean, and Crist, 1922).

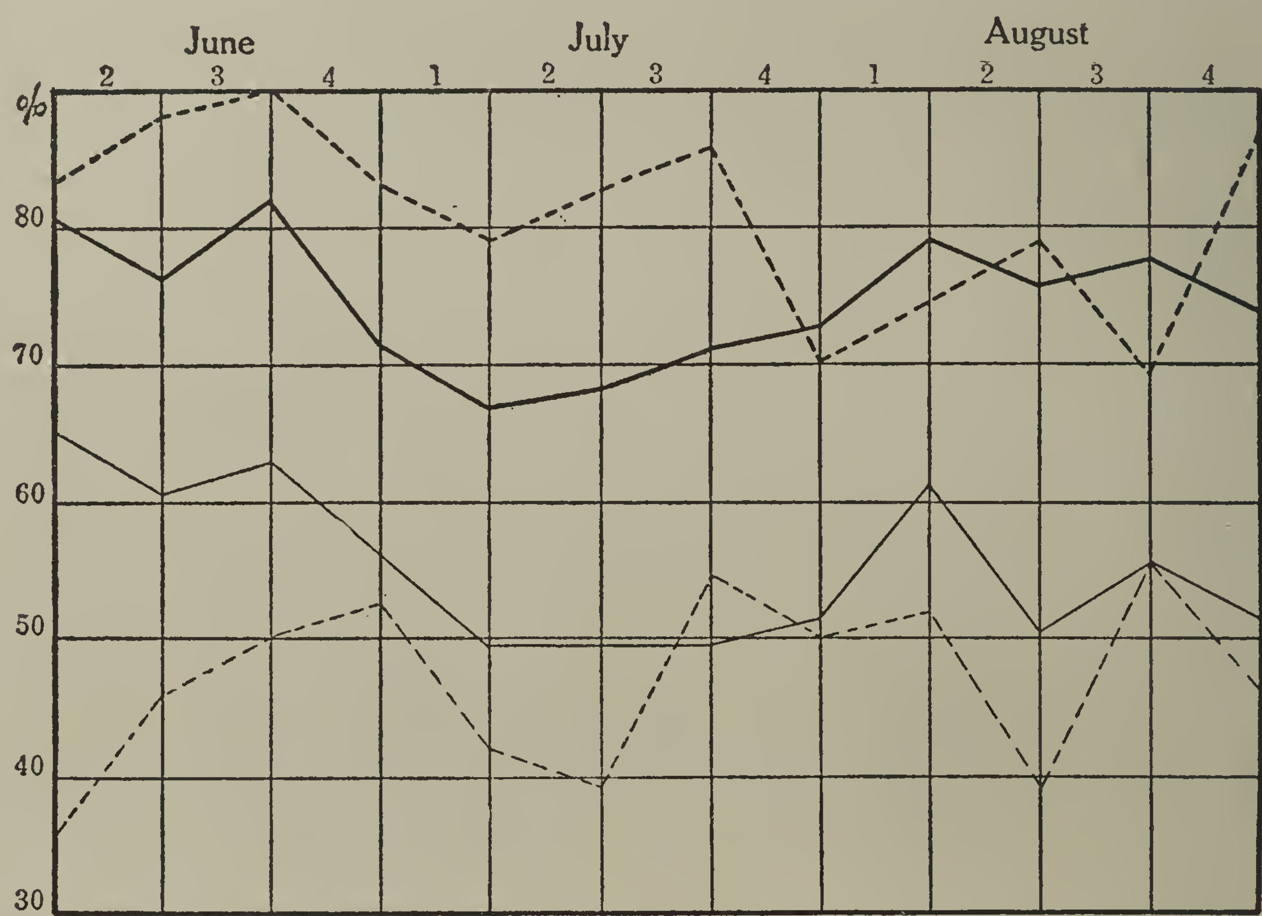

Fig. 7.—Average day (light lines) and night humidity (heavy lines) at Lincoln (solid lines), and Burlington (broken lines), 1920.

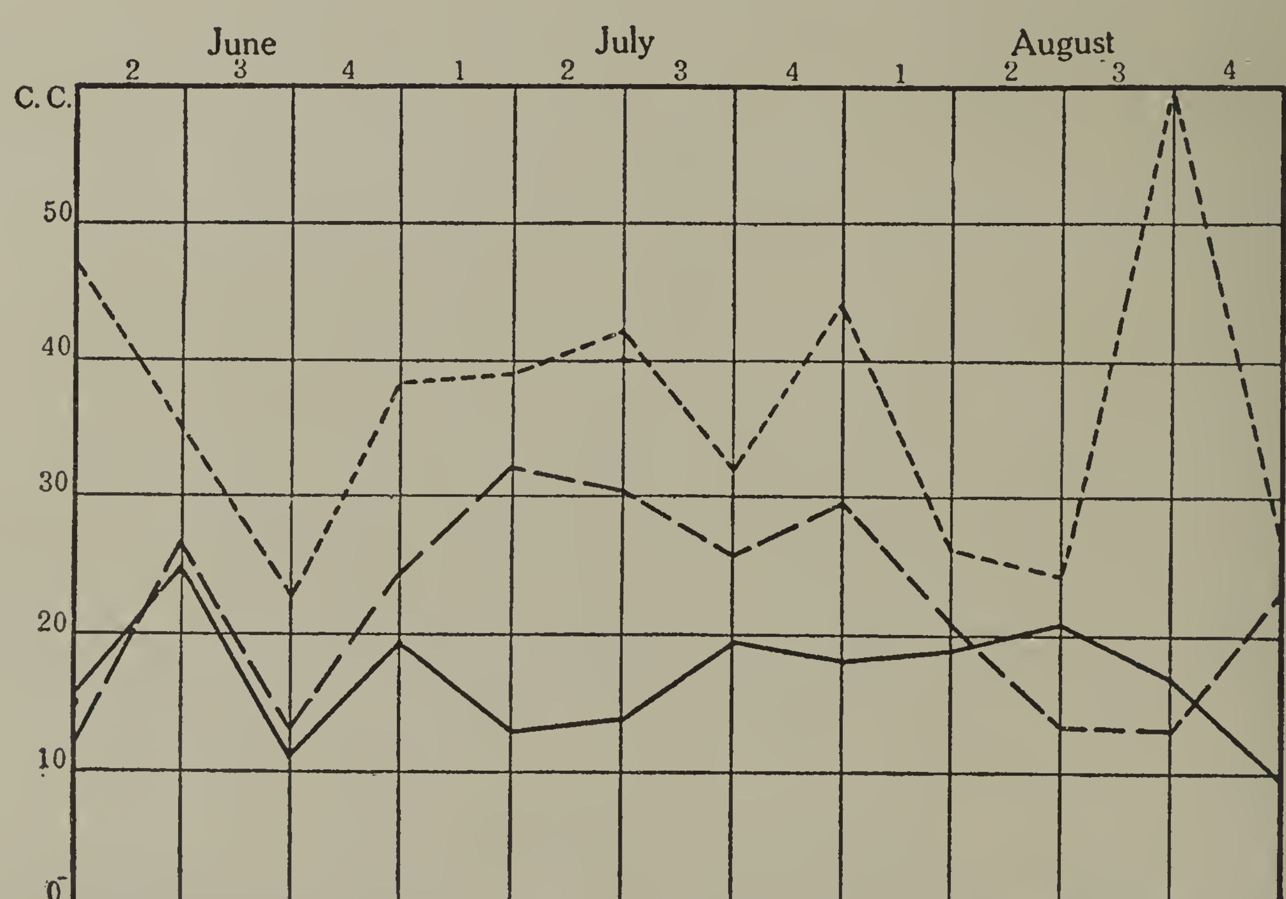

Fig. 8.—Average daily evaporation at Burlington (short broken lines), Phillipsburg (long broken lines), and Lincoln (solid line), 1920.

DETAILED METHODS.

Germination of Seed.

In these experiments the fruits and seeds of a large variety of grasses' forbs,[1] shrubs, and trees from a wide range of habitats were employed. These were collected in quantity, when ripe, chiefly at Lincoln, Nebraska City. and Halsey, Nebraska; Phillipsburg, Kansas; and Burlington and Colorado Springs, Colorado. In addition, others were secured from the vicinity of Berkeley, California; Tucson, Arizona, and in lesser quantities from other sources. After drying, the seeds were placed in large cloth bags and kept over winter in a dry, well-ventilated, unheated building at Lincoln. A new crop of seeds was secured each season. After threshing and cleaning the seed, germination tests were conducted in pots and flats in the greenhouse of the University of Nebraska, and to a less extent in moist chambers in the laboratory. This was primarily for the purpose of eliminating the species that germinated rarely or not at all, for it proved possible to sow seeds even with a low viability so thickly as to secure a good stand. Seeds from plants growing in sand, viz, *Calamovilfa longifolia*, *Muhlenbergia pungens*, *Redfieldia exuosa*, etc., were germinated in sandy soil.

The vitality of the seeds differed greatly from season to season, as would be expected. Among various causes for this, climatic conditions at the time of anthesis may have been a potent factor. In some cases, early frosts on lowlands proved harmful to the unripe seeds of late species of grasses. While the 1920 crop of *Kuhnia glutinosa* gave no germinable seeds, that of 1921 yielded 84 per cent. This is the highest record for any species, values of 20 to 25 per cent (*Psoralea tenuiflora*, *Ratibida columnaris*, *Stipa viridula*, *Amorpha canescens*, *Desmodium canescens*, and *Liatris scariosa*) being very good, while a germination of 10 to 15 per cent was quite usual. Some of the legumes germinated very slowly. A few species that did fairly well in the greenhouse (*Amorpha canescens* and *Aster multiflorus*) gave no germination under field conditions (1922).

Depth of Planting.

In dealing with seeds so variable in size and natural depth of planting (viz, *Sporobolus asper*, *Aster*, and *Solidago* as compared with *Stipa spartea* and *Gleditsia triacanthus*), great care was exercised to place the seed at such a depth as to favor germination and establishment. The results of a single greenhouse experiment upon this phase of the problem are of interest (table 8). In this experiment 50 seeds of each species were planted at various depths in loam soil of good tilth, except where the seeds, because of small size or low viability, were used in larger but equal (measured) numbers. Sandhill species were grown in sandy loam.

These results show that depth of planting has a pronounced effect upon germination and establishment. This is due in most cases to the actual failure of the seed to germinate at increased depth of soil and in others to its inability to grow through the greater thickness of soil and still have sufficient

[1] The term "forb" is here used for herbs other than grasses in order to afford a clear cut distinction and at the same time avoid an awkward phrase. It is derived from the Greek-Latin root which appears in φορβή and in *herba* (*ferb—).

Table 7.—*Germination of seeds.*[1]

Species.	1919.	1920.	1921.	1922.	1923.
Acer negundo[2]			Fair	Fair	
Acer saccharinum		Fair	Seeds frozen; no crop	Good	
Agropyrum glaucum			Poor	Good	None.
Amorpha canescens				Good	
Andropogon contortus[5]			Poor		
furcatus	Poor		Poor	Poor	Poor.
halli			Poor	Poor	
nutans	Poor	Good	Fair	Fair	Fair.
scoparius	Poor	Fair	None	None	Poor.
Argemone platyceras[3]				Poor	
Aristida purpurea[4]	Good	Poor	Excellent.	Good	Excellent.
Aster multiflorus			None	Fair	None.
salicifolius			None	None	
Astragalus crassicarpus			None		Fair.
Bouteloua bromoides[5]			Good		
eriopoda[5]			None		
gracilis		Good	Excellent.	Poor	Excellent.
hirsuta	Poor	Excellent.	Fair	Good	None.
racemosa		Fair	Poor	Excellent.	Poor.
racemosa[5]			Good	Fair	
rothrocki[5]			None		
Brauneria pallida			None	Poor	None.
Bulbilis dactyloides					Fair.
Calamovilfa longifolia[6]			Fair	Very poor	Poor.
Cassia chamaecrista					Fair.
Cornus canadensis[2]				Very poor	
Corylus americana[2]				Very poor	
Desmodium canescens					Excellent.
Elymus canadensis	Good	Excellent.	Excellent.	Good	Excellent.
Fraxinus lanceolata[2]		Poor	Fair	Fair	
Gleditsia triacanthus		Fair	Good	Good	
Glycyrrhiza lepidota			None	None	
Helianthus petiolaris[3]				None	
rigidus			None	None	None.
Hilaria rigida[5]			None		
Koeleria cristata		Excellent.	Excellent.		
Kuhnia glutinosa			None	Excellent.	Excellent.
Lespedeza capitata		Poor	Fair	Fair	Fair.
Liatris punctata		Excellent.	Good	Good	Good.
scariosa			Excellent.	Excellent.	Good.
Muhlenbergia pungens[6]			Fair	Fair	
Onagra biennis			Fair	Excellent.	Excellent.
Panicum virgatum	Poor	Fair	None	None	None.
Petalostemon candidus				Fair	Excellent.
Pinus ponderosa[7]		Good	Good	Good	
Psoralea tenuiflora[3]			None	Good	
Ratibida columnaris[3]				Good	
Redfieldia flexuosa[6]			None	Fair	
Rhus glabra			None	None	
Robinia pseudacacia[2]			Good	Good	
Salvia pitcheri					None.
Solidago missouriensis			None	Fair	
serotina			None	None	
rigida					Fair.
Sporobolus cryptandrus[3]			None	Good	
asper			Excellent.	Good	Excellent.
Stipa comata[3]	Poor	Good	Poor	Poor	
spartea		None	Poor	Poor	None.
viridula[3]	Good	None	Fair	Excellent.	Good.
Symphoricarpus occidentalis				None	
vulgaris				None	
Ulmus americana		Good	No crop, frozen	Good	

[1] All seeds were collected at Lincoln, unless otherwise indicated.
[2] Seed from Pennsylvania.
[3] Seed from Colorado Springs.
[4] Seed from Burlington.
[5] Seed from Arizona.
[6] Seed from sandhills, Halsey, Nebraska.
[7] Seed from Wyoming.

reserve material to establish itself. The decrease in the number of seedlings that appeared above ground was due in part to this cause, but especially to damping-off and other abnormal conditions arising under control. With the grasses a depth of planting exceeding 0.5 to 1 inch was distinctly detrimental, and most of them, like the composites, did best at 0.12 to 0.25 inch. Undoubtedly, aeration and frequency and amount of precipitation exerted a profound effect upon ecesis in the field. Even under uniform conditions, some seeds, e. g., *Elymus canadensis*, germinate and grow rapidly, while others are much slower, as would be expected.

Methods of Sowing and Planting.

Seeds and fruits of plants were sown under three different sets of conditions at the several field stations, namely, surface-seeding, trench, and denuded quadrat. Surface-seeding consisted of selecting areas with a typical cover of vegetation in which wooden stakes bearing the names of the species were driven. Near the stakes and without disturbing the surface, a small quantity of seed was scattered. A little débris was added to simulate conditions during fall and winter after the seeds have fallen naturally from the plant.

Table 8.—*Germination and depth of planting.*

Species planted Mar. 24.	Depth in inches.	No. of plants.					
		Apr. 1.	Apr. 4.	Apr. 7.	Apr. 14.	Apr. 25.	Remarks.
Aristida purpurea....	0.25	.....	8	9	5	4	3 lvs. Apr. 25.
	0.5	.....	8	23	23	23	Same size as those at 0.25 inch depth.
	1	.....	3	8	0	0	
	2	.....	0	0	0	0	
Agropyrum glaucum[1].	0.5	2	16	38	49	49	4 to 5 in. tall with 3 lvs., Apr. 25.
	1	4	18	29	25	25	Same size as preceding.
	2	2	4	15	14	4	All smaller than preceding.
	3	0	0	0	0	0	
Amorpha canescens...	0.25	9	11	10	8	9	
	1	3	7	7	5	5	Smaller than preceding.
	2	0	0	0	0	0	
	3	0	0	0	0	0	
Andropogon halli[1]....	0.25	5	2	4	2	3	2 in. tall, 3 lvs., Apr. 25.
	0.5	0	1	1	2	2	Same as above.
	1	0	3	2	2	2	Do.
	2	0	0	1	3	3	Nearly as large.
Andropogon nutans...	0.25	8	7	5	2	2	Tillering.
	0.5	0	1	1	1	1	As large as preceding.
	1	0	0	0	0	0	
	2	0	0	0	0	0	
Bouteloua racemosa[1]..	0.12	14	25	27	29	3	Progressively smaller to the maximum depth.
	0.5	20	25	17	14	0	
	1	1	25	25	32	17	
	2	0	8	15	8	3	
Bouteloua hirsuta[1]....	0.25	4	10	10	10	11	3 or 4 leaves; 1.5 in. tall.
	0.5	4	7	9	7	7	
	1	1	4	4	0	0	
	2	0	0	2	0	0	
Desmodium canescens.	0.25	2	6	16	18	18	Largest, with 5 leaves.
	1	5	11	23	24	24	Smaller than above.
	2	0	1	11	9	9	As large as 1 inch.
	3	0	0	0	0	0	

[1]Number of seeds not counted.

TABLE 8.—*Germination and depth of planting*—Continued.

Species planted Mar. 17.	Depth in inches.	No. of plants. Mar. 27.	Mar. 29.	Apr. 1.	Apr. 4.	Apr. 7.	Apr. 14.	Apr. 25.	Remarks.
Elymus canadensis.[1]	0.12	5	8	15	14	13	13	......	Poorest.
	0.5	6	16	16	16	18	18	......	About same size.
	1	0	24	24	24	29	27	......	
	2	0	13	26	28	28	22	......	Smallest.
Kuhnia glutinosa.	0.12	Thick.	Thick.	Thick.	Thick.	Thick.	Thick.	......	
	0.5	Thick.	Thick.	Thick.	Thick.	Thick.	Thick.	......	Smaller than above.
	1	A few.	Thick.	Thick.	Thick.	Thick.	Thick.	......	Do.
	2	0	0	0	0	0	0		
Liatris scariosa.	0.25	25	27	22	18	18	16	15	4 to 5 in. tall.
	1	0	0	0	0	0	0	0	
	2	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	
Liatris punctata.	0.25	1	12	12	13	13	12	11	2 to 3 in. tall.
	1	0	0	0	0	0	0	0	
	2	0	0	0	0	0	0	0	
	3	0	0	0	0	0	0	0	
Muhlenbergia pungens.[1]	0.12	......	20	20	12	8	8	7	2 tillers; 3.5 in. tall.
	0.5	......	20	40	50	44	35	35	
	1	......	12	16	12	12	10	10	Smaller.
	2	......	6	14	20	20	20	20	Smallest.
Onagra biennis.[1]	0.12	Very thick.	Very thick.	Very thick.	Very thick.	Very thick.	Very thick.	Very thick.	Excessive competition.
	0.5	13	20	28	35	40	Very thick.	Very thick.	Much competition.
	1	3	3	3	4	4	7	7	Largest rosettes of all.
	2	0	0	0	0	0	0	1	Very small.
Petalostemon candidus.	0.25	6	6	6	6	6	7	7	2 in. tall.
	0.5	1	1	1	1	1	1	1	0.5 in. tall.
	1	0	2	2	2	3	3	3	Smaller, very delicate.
	2	0	0	0	0	0	0	0	
Ratibida columnaris.	0.25	2	2	3	3	3	2	3	Rosettes with 4 to 5 lvs.
	0.5	2	2	3	3	3	3	4	Smaller.
	1	0	0	0	0	0	0	0	
Sporobolus asper.[1]	0.12	8	9	28	34	35	31	31	3 to 4 in. 4 lvs.
	0.5	5	9	20	24	22	27	27	Large as above.
	1	0	4	14	34	34	......	5	Pot waterlogged.
	2	0	1	2	2	4	2	1	Smaller than above.
Stipa viridula..	0.25	25	35	39	40	38	33	33	4 to 5 in. 3 lvs.
	1	20	22	22	24	23	23	23	Do.
	2	0	0	3	2	4	3	2	Much smaller.
	3	0	0	0	0	0	0	0	

[1] Number of seeds not counted.

This was sufficient to keep the seeds from being blown away. Upon germination, seeds sown under such conditions meet with keen competition from the established vegetation for water and nutrients below ground and for light above. The degree to which light intensity is reduced under the grassland cover has never been adequately emphasized, but frequently it is as low as 5 to 10 per cent, even early in the summer.

The trench method of seeding was used in order to remove competition both below and above ground for longer or shorter periods. Long, narrow trenches, approximately 4 inches wide and deep, were cut in the native sod. The soil from the trench was then thoroughly pulverized and all of the larger roots and rhizomes carefully removed, after which it was again replaced in the trench Enough additional surface-soil was added so that when firmly compacted the level of the trench was the same as that of the surrounding surface This detail is of fundamental importance, since the amount of run-off or the amount of water running into the disturbed area is thus determined. Stakes bearing the species name were then driven in place at about 12-inch intervals and the seeds planted, the soil firmed, and a little loose surface-soil added as a mulch. The rapidity with which rhizomes and neighboring roots invade this newly prepared area varies considerably with the type of vegetation and climate, as also the rate at which the grasses arch over the trench and reduce the light intensity

In the case of denuded quadrats, the native sod was removed to a depth of 4 or 5 inches over an area about 2.5 feet long and 16 inches wide. The soil was pulverized, the plant parts removed, and the surface brought to such a height as to be even with the surrounding sod after settling. One and sometimes two species were planted in each quadrat thus prepared. Rhizomes of *Corylus americana* and *Symphoricarpus vulgaris* and *occidentalis* were transplanted in 1921. Obviously, root and rhizome invasion from the sides would affect the area in the quadrat much more slowly than that in the trench, and this was also true of shading. Consequently, the quadrat method obviates both root and especially shoot competition for a considerable period, but certain other factors more or less unfavorable to growth are introduced.

Since the most critical period in the life of the plant is that of ecesis, the method of seedling transplants was also used. Seeds were germinated and the seedlings grown in an unheated greenhouse in loam in 2.5 to 4 inch flower-pots. The larger pots were used for those species which grew most vigorously and whose roots penetrated deepest. Planting was timed in such a manner that the seedlings were well established and 3 or 4 weeks old before transplanting them into the grassland, usually early in May. At this time trenches were prepared in the way already described, except that the subsoil in the trench was well watered before replacing the soil. The trench was half filled with soil, and the seedlings were then transplanted without injury by simply removing the entire contents of the pot as a core, placing this at the proper level in the trench, and firming the soil about it. A sufficient number of plants were available so that any injured in removing the pot were discarded. After watering again, the trench was brought to the proper level and a thin layer of loose soil applied. If the weather required it, the trenches were watered for a 10-day period during establishment. As with the other methods of planting, the plants were thinned from time to time to reduce competition when necessary. All the seedlings were grown at Lincoln and transported to the other stations as needed.

Finally, a fourth method was used, which consisted of transplanting mature plants or sods. Blocks of sod about 10 inches square were selected and cut with almost vertical sides to a depth of 8 or 10 inches and removed with the minimum disturbance of the underground parts above the level. The size

varied somewhat, depending upon the root-habit and nature of the soil. In transplanting *Bulbilis dactyloides, Bouteloua gracilis, Muhlenbergia gracillima,* and other species with fine, dense surface roots, the blocks were often larger but not so deep. Conversely, transplants from sandy or gravelly soil were necessarily smaller. Many forbs were also transplanted, care being taken to wrap each block securely in burlap for transportation. By this method of sod transplants, species were planted reciprocally among the different stations; for example at Lincoln, *Spartina cynosuroides* was transplanted from swamp to salt-flat, low prairie, high prairie, and gravel-knoll, care being taken to replant a control block in the swamp for a check. In transferring the blocks of sod, great care was taken to make a hole of the exact size, so that the transplant was in good contact at both the bottom and sides, just enough loose soil being added and firmly tamped around the block to make the contact complete. The sods were placed 2 or 3 feet apart. Ordinarily, root and rhizome growth had more or less obscured the lines of disturbance after the first season, unless there were marked differences in soil color or texture.

As far as possible, transplants were made preceding or coincident with the renewed growth and at a time when the holard was distinctly favorable. Moreover, green parts were clipped back, often level with the soil, in order to reduce water-loss. The surplus food materials of the older roots, rhizomes, etc., rendered vigorous growth possible, and in the main this was the most successful method employed, early-blooming species like *Koeleria cristata* and *Stipa spartea* alone sometimes failing to seed the first season. The others, such as *Agropyrum glaucum* and *Bulbilis dactyloides,* not only fruited, but often also extended their area by vigorous propagation.

2. EXPERIMENTS DURING 1920.

HIGH PRAIRIE, LINCOLN.

Surface Sowing.

Surface sowings of 6 species were made on the high prairie, April 16. The seed was obtained at Lincoln, as in all cases, except as otherwise stated, *Stipa viridula* from Colorado Springs being the only exception in this instance. *Koeleria cristata* and *Stipa* alone had germinated by May 15, and *Andropogon nutans* and *A. scoparius* by June 2, while the seeds of *Elymus canadensis* and *Aristida purpurea* (seeds from Burlington) did not germinate. By June 15, *Stipa* and *A. scoparius* were mostly dead or dying, and from this time there was a steady decline until August 30, when all had succumbed.

It is interesting to note that, although heavy rains occurred immediately after sowing and at two other intervals, only two species had germinated by May 15. Holard determinations show no indication of failing moisture in the surface 6 inches until the middle of June (table 6), but this is no criterion of the alternate periods of wetting and drying undergone by the seeds in the surface inch of soil. The drought during June was marked, no efficient precipitation falling from the 7th until the 25th; in fact, the rainfall was less

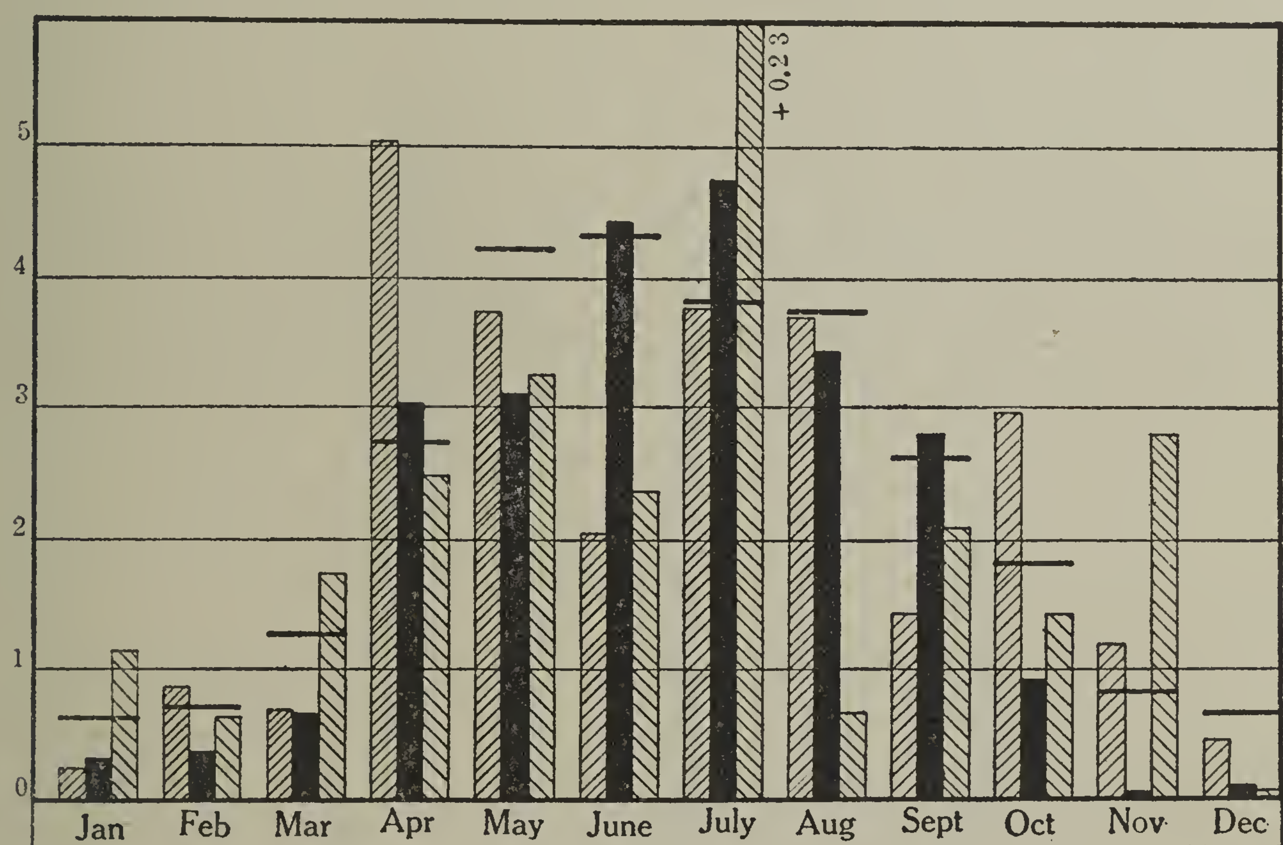

Fig. 9.—Monthly precipitation at Lincoln, 1920–1922; the monthly mean is shown by heavy cross-bars.

than half of the normal (fig. 9). Drought weakened the seedlings, but not to such an extent that they were unable to survive during the favorable growing weather of July and August, and competition for light undoubtedly played the decisive rôle. By late in May the light intensity at the soil surface (where the

prairie was burned the preceding spring) was reduced to 12.5 per cent, with a range of 2.5 to 26 per cent as determined by the stop-watch photometer, and later in the season this was much further decreased.

Trench Sowing.

The various species sown by this method all germinated, except *Koeleria.* The June drought resulted in the loss of 6 of the 12 species, nearly all of which were in fine condition early in the month. Five of the six remaining species not only survived the summer, but became permanently established. The failure of the four introduced species is of interest, especially since the holard was quite favorable for growth throughout the season (table 6). The attenuated condition of certain species noted was due to competition for light; by midsummer (July 25) the light values were only 20 per cent, even at a height of 4 inches above the surface, under a moderate cover.

Quadrat Sowing.

With three exceptions, all of the species sown on the surface or in the trench were also planted in denuded quadrats. Two plantings were made, one on April 16 and another on May 4 (table 58). Although the June drought made its impress upon the seedlings, all but three species, *Koeleria cristata Stipa comata,* and *S. coronata,* survived the summer. In fact, the following season showed that all of these were permanently established, except the California stipas, which were winterkilled. It is interesting to note that grasshoppers, while not attacking the native seedlings, greedily ate the introduced ones (except *Stipa viridula*). This alone might constitute a biological barrier. Little difference was noted in the success of the seedlings planted at different dates. At both plantings the soil was quite moist and good rains soon followed. Even a short period of drought after germination is often disastrous, as can be understood from a study of the life-history of the seedlings. Since it is extremely difficult to recover with certainty the delicate

Fig. 10.—Plants of *Bouteloua gracilis* (A), *Bouteloua hirsuta* (B), and *Sporobolus asper* (C), 44-days old; scale 1 foot.

roots among the dense tangle of the native sod, plants for this purpose were grown in a similar soil free from vegetation. In early growth these were comparable to those in the quadrats, though differences occurred later.

Root Habits of Seedlings.

Plants for root study were planted in fertile cultivated soil on April 20. The roots were first examined on June 3 and 4, when the plants were about 44

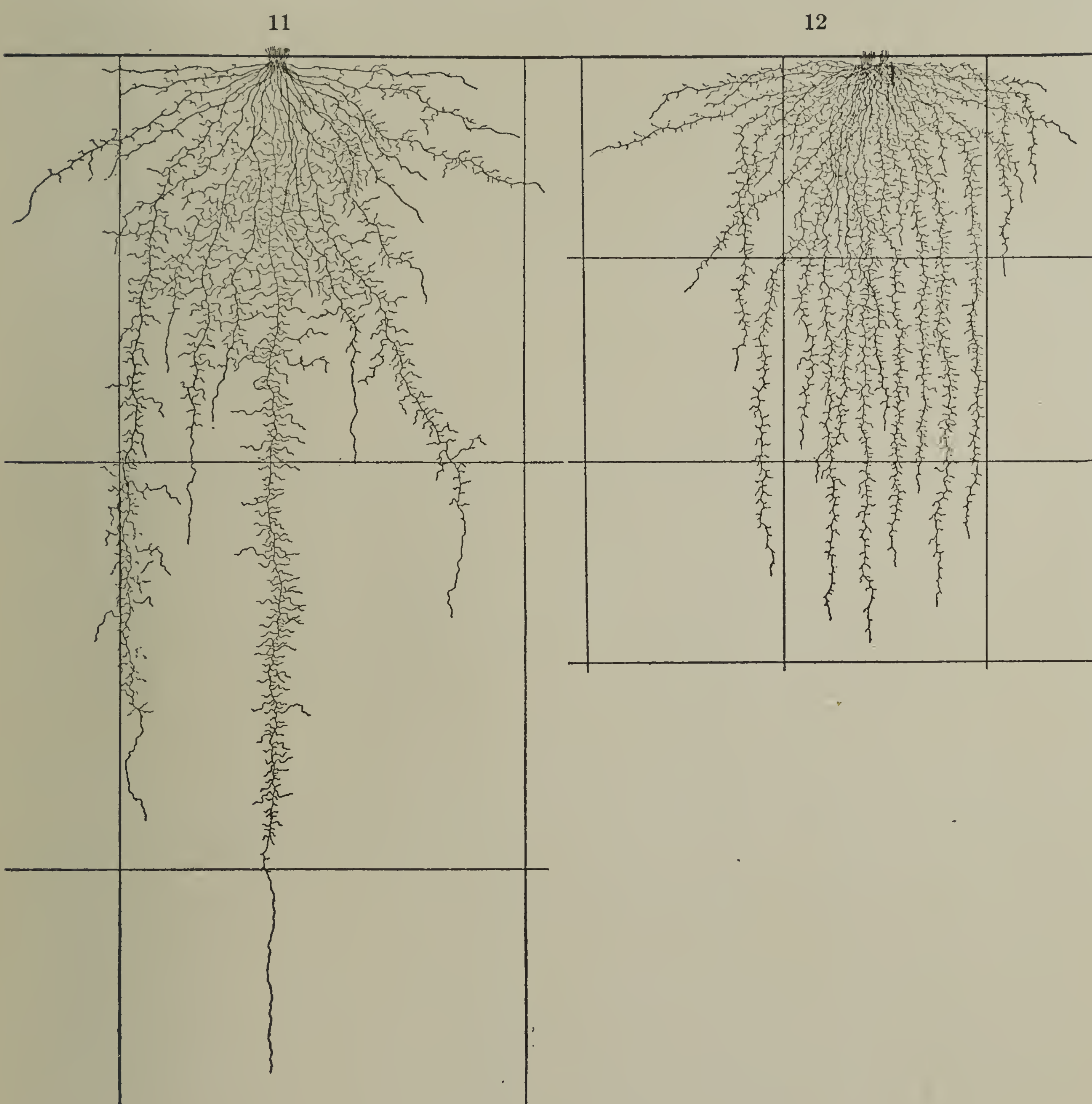

Fig. 11.—*Bouteloua gracilis* 3 months old.
Fig. 12.—*Bouteloua hirsuta* 3 months old.

days old. The plants of *Bouteloua gracilis*, *Sporobolus asper*, and *Bouteloua hirsuta* were 3 or 4 inches tall, each had 3 to 5 leaves, and most of them were beginning to tiller (figs. 10, A, B, C). The position of the seed and the pronounced branching of the single primary root are clearly evident, and the depth of 7 to 11 inches so early attained is significant. Tillering occurred simultaneously with the development of a secondary root system, a phenomenon which is common also to the cultivated cereals (Weaver, Kramer, and

Reed, 1923). The period of tillering, before the new roots have become well established in the moist layers of soil, is a very critical one for the plant, drought at this time often causing great mortality. Where a little erosion occurs, it may be plainly seen that the seedling is literally hanging on to life by a single thread.

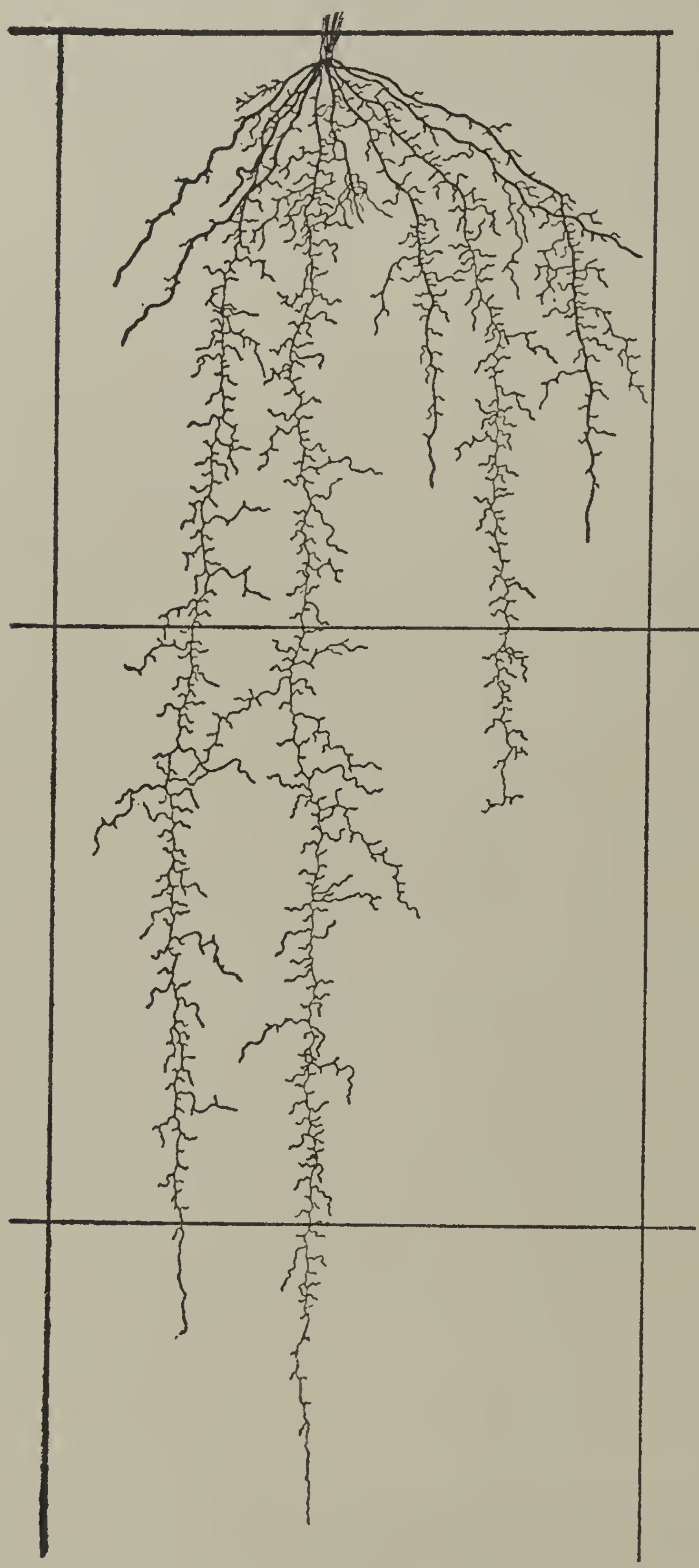

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Fig. 13.—*Stipa spartea* 3 months old.

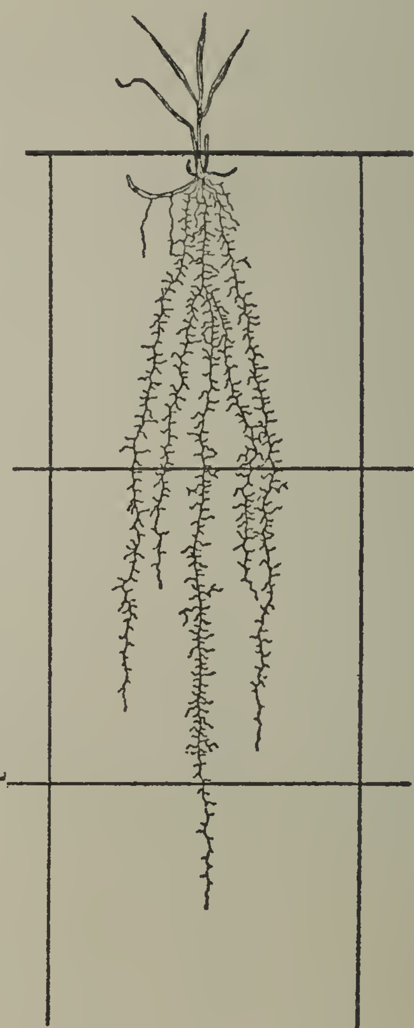

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Fig. 14.—*Agropyrum glaucum* 3 months old.

By July 11 to 14 the root development of *Bouteloua gracilis*, under the favorable growth conditions and lack of competition, had a height of foliage of about 8 inches, while flower-stalks 12 to 18 inches tall bore spikes of flowers almost in bloom. However, the plants in the quadrats were only 4 to 6 inches tall. The primary root was still plainly distinguishable from the abundant widely

spreading or deeply penetrating ones of the secondary system. The working-level was about 20 inches; some roots reached depths of 33 inches (fig. 11). *Bouteloua hirsuta* was even more deeply rooted than the preceding, although its above-ground parts were scarcely so well developed (fig. 12). The root penetration of *Stipa spartea* was similar to that of the gramas, though the two or three roots of the primary system alone had penetrated deeply, the larger fleshy branches of the secondary system mostly ending at a depth of about 8 inches. The plants were 8 to 10 inches tall; the parent plants had about 5 leaves and some were well tillered (fig. 13).

The development of *Agropyrum glaucum* is shown in figure 14. *Aristida purpurea* at this time had formed heavily tillered clumps 6 to 8 inches tall, which were only slightly better developed than those in the prairie quadrats. The roots had a working depth of 20 inches and a maximum penetration of 32 inches. Plants of *Elymus* with a height of 12 to 15 inches (compared with 5 inches in the quadrats) showed a similar root depth. *Stipa viridula,* which also grew more vigorously in these plats, with a height of 8 to 10 inches, had a working level of 16 inches, while the longer roots penetrated 33 inches into the moist soil. These data show clearly why a species, after the hazards of the first season are past, has much greater chances of survival.

Summary of Planting Results.

With respect to results on high prairie, the germination on the surface, in the trench and in the quadrats was 66, 92, and 100 per cent respectively, and the survival, 0, 45, and 80 per cent. Most of the introduced species were badly damaged by grasshoppers, although some in the quadrats survived the season but were winterkilled. Aside from these, all the species that persisted to the end of the first season became permanently established. *Andropogon scoparius*, *A. nutans*, and *Bouteloua gracilis* grew well in both trench and quadrat.

Sod Transplants.

Sods of the following species were planted on April 23, mostly in triplicate. All showed some drought effects during June, such as rolling of the leaves, but most species grew normally and all survived. Among those from the high prairie, *Agropyrum glaucum*, *Elymus canadensis*, *Koeleria cristata*, and *Stipa spartea* produced seed, while *Andropogon scoparius* and *Bouteloua racemosa* failed to form flower-stalks. *Bouteloua gracilis* from the gravel-knoll did not blossom, but *Distichlis spicata* from the salt-flat seeded profusely. *Andropogon nutans* was the only species from the low prairie which did not fruit, *A. furcatus*, *Poa pratensis*, *Panicum virgatum*, and *Spartina cynosuroides* all producing seed.

MIXED PRAIRIE, PHILLIPSBURG.

Surface Sowing.

Seeding was done on May 7 with the same six species as those used at Lincoln. When examined on June 10, three species only had germinated, but these were quite abundant. By July 1, two, *Koeleria cristata* and *Stipa viridula,* had died, while *Elymus* was represented by a few slender narrow-leaved plants with dead tips, which succumbed by July 10. Good rains

occurred soon after planting and at two later periods in May. However, an examination of the rainfall data shows that the precipitation for June was much less than half of the normal, as at Lincoln (fig. 15). No rains sufficient even to wet the surface-soil fell after June 18 until the 14th of July, when drought again prevailed until late July (table 6). The attenuated condition of the longer-lived species was due to the competition for light. An average value of 28 per cent (range 2.8 to 80 per cent) was determined for this station on June 11.

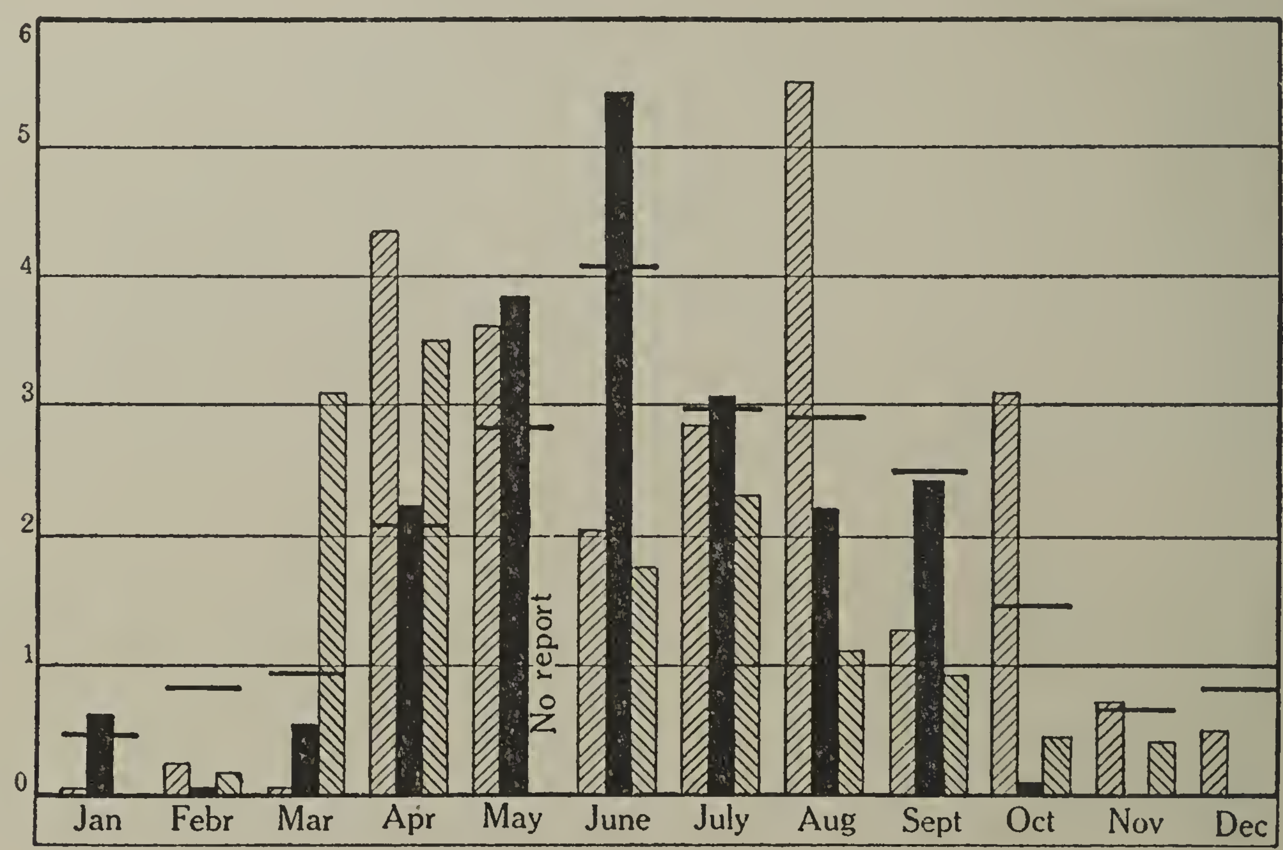

Fig. 15.—Monthly precipitation at Phillipsburg, 1920–1922; the monthly mean is shown by heavy cross-bars.

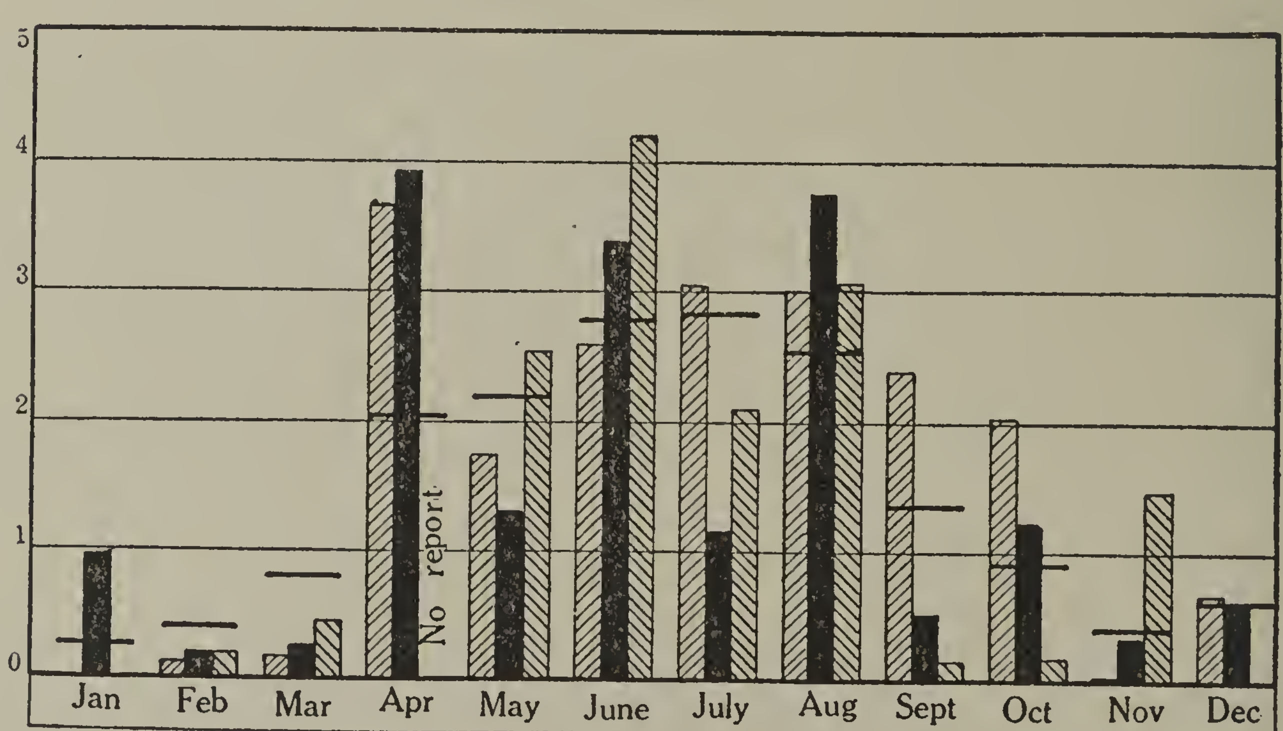

Fig. 16.—Monthly precipitation at Burlington, 1920–1922; the monthly mean is shown by heavy cross-bars.

Trench and Quadrat Sowing.

The behavior of the same species, sown in the trench, is summarized in table 9. While all germinated, two died by July 1, another by August 4, and only two, *Andropogon scoparius* and *A. nutans*, grew throughout the season and became permanently established. These plants, with others, did much better in the quadrats. While all but *Aristida* germinated by July 1, several showed a high mortality due to drought, although only two species had died. Conditions became drier during July and only six species were represented by the end of the summer. All of them became permanently established, *Bouteloua gracilis* forming flower-stalks the first season.

Thus, there was a mortality of 100 per cent among plants where the seed was surface-sown, while 33 per cent survived in the trench, and 67 per cent in the quadrats. *Andropogon scoparius* and *A. nutans* did well in both trench and quadrats, but *Bouteloua gracilis* alone flowered the first year. No sods were transplanted at this station.

SHORT-GRASS PLAINS, BURLINGTON.

Surface Sowing.

The account of the growth of surface-planted species at Burlington is brief. Of the 13 species sown on April 15, evidences of germination were found for only 6 on June 11, and the plants of two of these species were dead. By July 2, three species alone remained, and one of these, *Liatris punctata*, died before the end of the summer. *Bouteloua gracilis* merged into and became scarcely distinguishable from the native sod; *Stipa viridula* tillered heavily and was over 6 inches tall.

Precipitation records show that showers (0.25 to 0.63 inch) fell in April after seeding, but this was followed by no efficient rainfall (0.15 inch or more) until the middle of May. Another drought period intervened until the 27th, when 0.25 inch of rain fell, after which drought ensued until June 18, all of this serving to emphasize the unfavorable conditions to which the plants were subjected (fig. 16). The almost constant lack of rainfall throughout the summer was enhanced by the frequent high winds, low humidity, and high evaporation (figs. 7 and 8).

Trench and Quadrat Sowing.

Thirteen species were sown in the trench on April 15. Evidence that *Andropogon nutans* and *Elymus canadensis* had germinated was found, but both species had died and none germinated later. With one or two exceptions the same species that were sown on the surface and in the trench were also planted in denuded quadrats. Their growth throughout the season is shown in table 60. Seven of the 13 species germinated; all but four were dead by July 2, and only three species, *Andropogon nutans*, *Stipa viridula*, and *Liatris punctata*, became established.

A summary shows that 33 per cent of the surface-sown species that germinated survived; all of those in the trench succumbed, while in the denuded quadrats 43 per cent lived through the season and as usual became established. *Stipa viridula* survived both on the surface and in the quadrats, *Bouteloua gracilis* on the surface, and *Andropogon nutans* and *Liatris punctata* in the quadrats.

Sod Transplants.

Blocks of sod of the following species, mostly in quadruplicate, were secured from the several stations at Lincoln and planted at Burlington: *Agropyrum glaucum, Andropogon scoparius, A. furcatus, Bouteloua racemosa, Elymus canadensis, Koeleria cristata, Panicum virgatum, Poa pratensis,* and *Stipa spartea.* Before planting the sods in the holes made in the short-grass mats, these were filled with water, which was allowed to sink into the deeper layers before the block was tamped in place. The grasses were planted in two long rows, each having two blocks of each species, and several feet of unbroken sod thus intervened between the blocks. After planting, all were thoroughly watered, and this was repeated on one row at intervals of 2 or 3 weeks throughout the season, as proved necessary. It was found later that the watered row, which had been planted only 2 or 3 feet from a broken area, had received some run-off water from the furrow separating the broken field from the grassland.

Although none of the transplants died, the drought affected the unwatered row in a number of ways, while even the watered plants did not attain normal development. Nearly all of the former exhibited a marked rolling of the leaves and even severe wilting at times, and the tips on several species as well as whole plants died back considerably. *Elymus, Koeleria, Panicum,* and *Stipa* flowered under both conditions, but the flower-stalks were usually fewer and decidedly shorter in the unwatered row, as was true of the foliage also. Thus, the maximum leaf-height of *Panicum* under the two conditions was 13 and 20 inches respectively, while the height of the panicles ranged in the one case from 7 to 13 and in the other from 19 to 20 inches. *Stipa, Koeleria,* and *Elymus* seeded in both habitats, but *Agropyrum* and *Andropogon furcatus* in neither, while *A. scoparius* and *Bouteloua racemosa* each had a single flower-stalk in the watered area. The ultimate fate of these transplants is indicated on pages 68–70.

Summary of Experiments.

The results of the 1920 experiments at the three stations are summarized in table 9.

Table 9.—*Summary of experimental seeding, 1920.*

Method.	Per cent of germination.[1]			Per cent of germinated species established.		
	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.
Surface-sowing......	66	50	46	0	0	33
Trench.............	92	100	15	45	33	0
Denuded quadrat....	100	90	54	80	67	43
Average........	86	80	38	42	33	25

[1]As indicated elswhere, it is entirely possible that some seeds germinated, but did not appear above ground, or died later and disappeared between visits to the stations, though it seems probable that few remnants were overlooked.

Of the plants surviving, only three, *Andropogon nutans, Bouteloua gracilis,* and *Stipa viridula,* succeeded under at least one condition at all three stations.

Andropogon scoparius and *Bouteloua hirsuta* grew at all stations but Burlington, and *Liatris punctata* at all but Lincoln. *Elymus*, *Bouteloua racemosa*, and *Aristida purpurea* lived throughout the season at Lincoln only. In most cases a somewhat better growth occurred at Lincoln than westward. For example, *Andropogon nutans* was 7 to 10 inches tall at Lincoln, 6 to 9 inches at Phillipsburg, and 4 to 5 inches at Burlington late in August. Among the transplanted, about 70 per cent flowered at both Lincoln and Burlington, those at the latter station having been watered. Of the unwatered sods at Burlington, 53 per cent had flower-stalks, but some had only one each. While the transplants at Lincoln developed quite normally, most of those at Burlington were much dwarfed, even when watered.

SEEDING IN CULTIVATED AREAS AT ALL STATIONS.

True Prairie.

The germination and growth of the preceding species in cultivated soil at the several stations is instructive. In every case a good seed-bed was prepared by plowing, disking, harrowing, etc., and a part of the fields used in growing experimental crop-plants (Weaver, 1920, 1922) was set aside for native vegetation. Weeds were removed from time to time by hoeing. In these experiments the trench method alone was used. The upland station at Lincoln was located on a broad, level hilltop of silt loam adjoining the upland prairie.

All but two species, *Aristida purpurea* and *Bouteloua hirsuta*, germinated, and all of the others except *Koeleria* came through the first season successfully. Because of the lack of the root competition which is regularly encountered by plants in the native prairie, these plants suffered less from midsummer drought. The tillering was much heavier and the plants were in all respects more vigorous. For example, *Andropogon nutans* was 7 to 10 inches tall in the prairie quadrats and 12 to 17 inches in the field on August 30. *Elymus* was 4 to 8 inches and 10 to 14 inches tall and *Bouteloua gracilis* 4 and 9 inches respectively in the two habitats. Like *Bouteloua racemosa*, both were putting forth flower-stalks in the cultivated field. They all seeded by October, together with *Andropogon scoparius*, although the flower-stalks of *Andropogon* and *Elymus* were dwarfed.

Fig. 17.—Root of *Liatris punctata* at end of first season's growth.

Root Development.

The striking growth made by these native species in a single season emphasizes the effect of the removal of competition, as shown especially by the root development, e. g., *Andropogon scoparius*, with a maximum penetration of 4 feet (plate 3A). Fully mature plants excavated in the prairie in similar soil differed mainly in their greater depth of penetration, about 5.5 feet (Weaver, 1919:4). *Stipa viridula* (plate 3B) had a well-developed root system, a few of the longer roots extending to the 33-inch level, but compared with the roots of mature plants in the native habit at the root system had scarcely

begun. At Colorado Springs they had a lateral spread of over 1.5 feet and a working level of nearly 11 feet. The roots of *Elymus canadensis* underwent a remarkable development, as shown in plate 4A, and as with mature specimens, most of the roots were in the first 1.5 feet of soil. However, this year-old plant exceeded in depth (34 inches) any excavated in grassland, and especially in the large number and profuse branching of its roots. *Liatris punctata*, though only 3 inches tall and with but 2 leaves, possessed a tap-root that penetrated to a depth of 3.3 feet (fig 17). A considerable supply of reserve food had been stored in the enlarged portion of the tap, which had a maximum diameter of 5 mm. Mature plants reached depths of 6 to 15 feet.

Both tops and roots of *Bouteloua racemosa* made exceptional growth; one plant was photographed and excavated on August 25, 1919, only 124 days after the seed was planted in the greenhouse on April 23, the seedlings having been transplanted to the field on May 10 (plate 4B). Mature plants reached depths of 5.5 feet. *Stipa comata* and *Andropogon nutans* attained working-levels of 18 and 28 inches respectively and maximum depths of 34 and 48 inches. The root habit and extent in both cases were similar to those of mature plants (plate 4C).

Mixed Prairie and Short-grass Plains.

At Phillipsburg, six species were planted on May 7 in a field adjoining the prairie station. *Andropogon nutans*, *A. scoparius*, and *Koeleria cristata* did not germinate, *Aristida purpurea* grew until midsummer only, while *Elymus canadensis* and *Stipa viridula* both prospered. By July 10 the two tillers on each plant of *Elymus* were practically as tall as the parent, but, unlike the plants at Lincoln, none produced flower-stalks.

At Burlington the plantings were made on the same day as in the grassland, viz, April 15. The following either did not germinate or died soon after germinating: *Andropogon nutans*, *A. scoparius*, *Aristida purpurea*, *Bouteloua gracilis*, *B. racemosa*, *Koeleria cristata*, *Liatris punctata*, *Panicum virgatum*, *Stipa comata*, and *S. setigera*. *Stipa viridula* made excellent growth throughout the summer, reaching a height of 8 to 12 inches. A thick stand of *Elymus canadensis* was obtained, but the plants died during the summer.

To summarize, germination of 83, 50, and 18 per cent respectively was obtained at the several stations going westward. Among those which germinated, *Koeleria* died at Lincoln and *Aristida* at Phillipsburg. *Elymus* was successful at these two stations, but flowered only at Lincoln. *Stipa viridula* succeeded at all three stations, doing quite as well or even better westward. Seven other species grew at Lincoln but not elsewhere. The holard of the cultivated fields decreased in nearly the same proportion as in the grassland at the several stations. The response of the seedlings to the different climates was in close agreement with that of the seedlings and transplants in the grassland.

EXPERIMENTS AT OTHER CLIMATIC STATIONS.

Subclimax Prairie, Nebraska City.

Character.

The subclimax-prairie station was located near Nebraska City, on a gentle east slope somewhat over halfway down one of the large rolling hills char-

acteristic of the topography of the region. It was situated in an area of native grassland of over 125 acres in extent. The soil is a dark-brown fine silt loam, consisting of glacial materials intermixed with loess. Below 1.5 feet it is quite yellowish in color and shows more plainly its loess origin. The high percentage of clay and silt is indicated by its hygroscopic coefficient, which is about 12 per cent; hence it is very retentive of moisture. As already indicated, the precipitation at this station is approximately 5 inches greater (33 inches) than at Lincoln. This additional moisture promotes the growth of a more luxuriant grassland vegetation and permits the presence of a large number of herbs and shrubs found rarely or at least much less abundantly in true prairie (plate 7B).

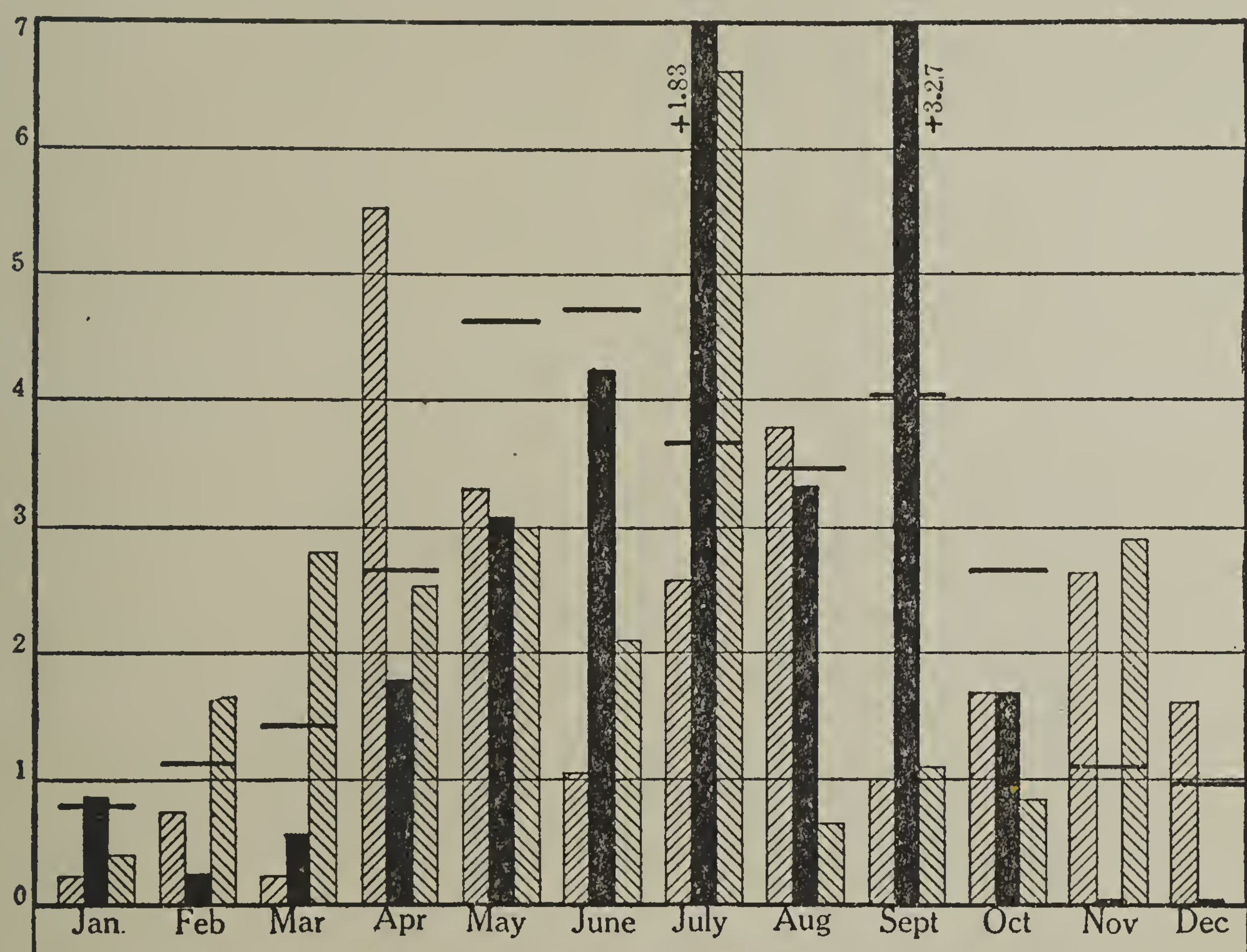

FIG. 18.—Monthly precipitation at Nebraska City, 1920–1922; the monthly mean is shown by heavy cross-bars.

As shown in figure 18, April had about twice the normal amount of precipitation. Moreover, this was well distributed and probably accounts for the high percentage (80) of germination. However, the rainfall of May was far below normal, while that of June was less than one-third the usual amount, only two rains falling (0.35 inch on the 15th and 0.70 on the 25th). July was likewise a dry month.

The dominant grasses are *Andropogon nutans*, *A. furcatus*, *A. scoparius*, and *Stipa spartea*. *Koeleria cristata*, *Poa pratensis*, *Bouteloua racemosa*, *Panicum virgatum*, and *Spartina cynosuroides*, which runs far up the ravines, are of lesser importance. The regular occurrence of *A. furcatus* and *Panicum* on highland and their excellent development indicate more favorable conditions for growth than in true prairie. The seasonal aspects and herbaceous societies resemble those described for Lincoln (Pound and Clements, 1900; Thornber, 1901). Throughout the grassland, even on the ridges, postclimax communities of *Ceanothus ovatus*, *Amorpha canescens*, and *Rosa arkansana* occur, being held in check by annual mowing. *Symphoricarpus vulgaris* and *occi-*

dentalis, Corylus americana, Cornus asperifolia, Rhus glabra, and *Xanthoyxlum americanum* invade the grassland from the vantage-ground of fences, hedge-rows, and ravines. In unmown and unpastured areas these with others, including many trees, form thickets or groves overrun with *Vitis, Rubus, Ampelopsis, Celastrus, Smilax,* etc., indicating the approach to climax conditions.

Results.

On April 2, ten species were sown on the surface of an area mown the preceding fall. *Aristida purpurea* and *Bouteloua gracilis* failed to germinate. *Stipa viridula, S. comata* (like *Aristida,* from seed collected at Colorado Springs), *Koeleria cristata,* and *Liatris punctata* died by midsummer, while *A. scoparius, A. nutans, Bouteloua hirsuta,* and *Elymus,* after suffering somewhat severe mortality, came through in good condition and became permanently established.

Table 10.—*Holard in excess of hygroscopic coefficient, Nebraska City, 1920.*

Date.	0.0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 2.....	24.2	21.3	18.3	14.2	12.6
June 6.....	14.2	16.9	17.9	....	....
June 14.....	16.7	10.6	....	....	....
June 21.....	8.4	6.7	12.8	....	....
June 30.....	8.9	7.9	....	....	....
July 4.....	9.8	4.7	7.1	....	....
July 19.....	4.5	5.3	7.3	8.9	9.9
July 28.....	2.3	3.4	4.9	....	....
Aug. 4.....	0.3	1.2	3.4	6.1	7.6
Aug. 12.....	9.7	2.6	3.1	....	....
Aug. 19.....	28.5	3.9	2.4	....	....
Aug. 28.....	12.4	9.5	5.2	3.3	5.5
Hygroscopic coefficient.	12.1	11.7	12.3	13.7	12.9

The attenuation of the leaves of the seedlings became noticeable early in June. By this time the average level had reached 11 inches, above which *Stipa* (3 feet), *Euphorbia corollata, Silphium integrifolium,* and various other herbs occurred. Light values ranged from 2.5 to 40 per cent.

The behavior of the species planted in the trench was exceptionally good. All germinated and all but four lived through the season, owing to the rather favorable chresard of early summer, which promoted rapid root growth (table 10).

The same species planted in the quadrats did much better. All germinated, became established, and lived throughout the summer. As usual, a fairly high mortality occurred among most species at the critical period, when the primary root system was supplying a maximum of transpiring area before the secondary one became established. As a consequence, the seedlings thrived best or held out longest about the edges of the quadrats. In solving this problem a comparison of conditions within the disturbed area, as compared with that in the undisturbed grassland, is illuminating.

Table 11.—*Comparison of chresard and soil temperatures in denuded quadrats and in adjacent undisturbed grassland.*

Station.	Date.	Depth.	Chresard.			Remarks.
			Grass-land.	Denuded quadrat.	Differ-ence.	
		inches.	*p. ct.*	*p. ct.*	*p. ct.*	
Lincoln, high prairie.	July 14	0 to 6	22.0	14.0	8.0	
	..Do...	6 to 12	16.8	12.1	4.7	
	June 14	0 to 6	6.8	11.3	−4.5	
Lincoln, low prairie..	Do...	0 to 6	10.7	19.9	−9.2	
	..Do...	6 to 12	13.8	20.2	−6.4	
	June 22	0 to 3	6.9	−0.6	....	
	..Do...	3 to 6	....	13.3	....	
Nebraska City......	June 21	0 to 3	2.0	−4.2	....	
	..Do...	3 to 4	....	17.9	....	
	..Do...	0 to 3	....	−2.6	....	
Phillipsburg........	May 19	0 to 3	....	5.8	....	
	..Do...	0 to 6	5.4	12.9	7.5	

Station.	Date.	Depth.	Temperature.			Remarks.
			Grass-land.	Denuded quadrat.	Differ-ence.	
		inches.	*°C.*	*°C.*	*°C.*	
Lincoln, high prairie.	May 5	Under surface	27.6	16.2	11.4	1 p. m., clear, hot.
Lincoln, low prairie..	...Do...	...Do.......	22.5	19.5	3.0	12 noon, clear, hot.
Lincoln, gravel-knoll.	June 14	3	26.5	21.2	5.3	2 p. m., clear, hot.
Lincoln, high prairie.	...Do...	Under surface	37.0	41.0	4.0	Do.
Lincoln, low prairie..	...Do...	1	34.0	47.0	13.0	2 p. m., burned area.
Do..............	...Do...	3	30.0	38.0	8.0	Do.
Lincoln, gravel-knoll.	...Do...	1	41.5	46.0	4.5	2 p. m., clear, hot.
Do..............	...Do...	3	37.5	41.0	3.5	Do.
Nebraska City......	June 21	Under surface	58.0	38.2	19.8	2^h30^m p. m., clear, hot.
Do..............	...Do...	3	37.6	32.4	5.2	Do.

It is evident that it is often much drier in the quadrats, the soil hotter, and the humidity much lower. The average daily evaporation is from 15 to 40 per cent higher in the bare area. These conditions are obviously unfavorable for seedlings. The partial shade about the edges of the quadrats lowers the temperature, lessens wind movement, increases the humidity, and undoubtedly accounts for the seedlings growing here when drought kills them elsewhere.

Mixed Prairie, Colorado Springs.

Character.

The station at Colorado Springs was located on a hillside sloping gently southward and in the midst of a great expanse of mixed prairie, about 2 miles

east of the city. As typical for much of the region, the soil consists of a light-colored loam intermixed with some sand. It is very compact and run-off is high; at a depth of 6 to 10 feet it is underlaid with sand. The distribution of the rather meager precipitation (15 inches) throughout the year is very similar to that for other stations. The holard of the surface foot is about 45 per cent and the echard 8.2 per cent. Studies of the water-content throughout a number of years show that it is frequently reduced to the hygroscopic coefficient in the surface layers, and the soil may become very dry to a depth of at least 4 feet. The high evaporation, which is often twice as great as in true prairie, accentuates drought. The extremes of day and night temperature are similar to those at Burlington. The high day temperatures cause low humidity (frequently 5 to 15 per cent) in the afternoon and corresponding water-loss from both plants and soil.

The climate is reflected in the composition of the grassland, both in the absence of many true-prairie species and the relative dwarfing of the others that grow in this habitat. As a result of close grazing before fencing the station, *Bouteloua gracilis* was quite dominant. Other short-grasses or sedges were *Muhlenbergia gracillima* and *Carex pennsylvanica*. *Stipa comata*, *Andropogon scoparius*, *Agropyrum glaucum*, *Aristida purpurea*, *Koeleria cristata*, *Bouteloua racemosa*, and *Andropogon furcatus* all reappeared after cattle were excluded, the latter only sparsely. *Artemisia frigida*, *Aragalus lamberti*, *Lupinus argenteus*, *Senecio aureus*, *Abronia fragrans*, *Chrysopsis villosa*, *Psoralea tenuiflora*, and *Argemone platyceras* all form extensive societies. *Ratibida columnaris*, *Opuntia camanchica*, *O. fragilis*, and *Thelesperma trifidum* were somewhat abundant. Most of the grasses are rooted at a depth of 3 to 5 feet, while many forbs penetrate much more deeply, some to 12 feet. This grassland never reaches the luxuriance of true prairie and consequently light played a very minor rôle in the following experiments.

Results.

The seeds of 9 species were planted in quadrats, but not until June 17. All were from Lincoln except *Aristida purpurea* and *Stipa viridula*. *Bouteloua gracilis*, *B. hirsuta*, and *Koeleria* failed to germinate, while *Liatris punctata* died soon after germination. *Andropogon scoparius*, *A. nutans*, *Elymus canadensis*, and *Stipa viridula* became established, but like the others were watered from time to time.

On June 9 the following sods from Lincoln were transplanted, being abundantly watered at the time of planting and at several intervals afterward: *Agropyrum glaucum*, *Andropogon furcatus*, *A. scoparius*, *Bouteloua racemosa*, *Bulbilis dactyloides*, *Elymus canadensis*, *Koeleria cristata*, *Panicum virgatum*, and *Stipa spartea*. Although they made a rather poor growth, due partly to the late period of transplanting, all survived the first season.

EXPERIMENTS AT EDAPHIC STATIONS.

Gravel-Knoll Station.

Character.

A comprehensive series of edaphic stations was located at Lincoln, all within a distance of a half-mile, ranging from gravel-knoll through high prairie, low prairie, lowland cultivated field, and salt-flat to swamp.

The gravel-knoll station, which was only 300 feet south of the high prairie, occupied the crest of a steep hill about 60 feet above the valley of Salt Creek (plate 5A). The soil is a drift and consists of very porous coarse sandy to gravelly loam with a water-holding capacity of only 40 per cent of its dry weight. At a variable depth, about 4 feet, it is underlaid with clay. The hygroscopic coefficients at the several depths, together with the chresard during 1920, are given in table 12.

TABLE 12.—*Holard in excess of hygroscopic coefficient.*

Date.	0.0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 21	13.3	7.3	13.3	....	....
May 5	14.2	5.5	15.1	....	....
June 9	4.6	5.1	....	....	....
June 16	−0.2	0.0	4.1	6.6	....
June 23	−1.1	−0.2	1.8	....	....
July 15	−0.9	1.7	2.6	1.1	5.8
July 29	−1.8	−0.6	8.1	....	....
Aug. 5	−1.9	−1.7	0.5	1.4	7.2
Aug. 12	3.3	−1.3	0.4	....	....
Aug. 19	8.6	2.3	0.3	....	....
Aug. 31	Continued heavy rains; no samples taken.				
Hygroscopic coefficient.	5.2	4.9	3.1	2.8	7.4

The low water-content is due not alone to the nature of the soil, but also to the steep and generally south slope, which produces a high run-off and greatly increases the temperature. These factors, together with greater wind movement and higher evaporation than at the high-prairie station, subject both soil and vegetation to frequent drought. The area was dominated by rather open mats of *Bouteloua gracilis* intermixed with *B. hirsuta*, which *Stipa spartea*, *Andropogon*, and other tall-grasses were invading with difficulty from their foothold in the silt loam farther down the slope. However, the transition from one soil type to the other is quite abrupt and the ecotone correspondingly sharp, a narrow belt of what is essentially mixed-prairie occupying this area.

BEHAVIOR.

Of the seven native species sown in the trench on April 16, *Aristida purpurea* and *Liatris punctata* failed to germinate. *Elymus canadensis* and *Koeleria cristata* were all dead by July 15, together with *Stipa coronata* and *S. setigera*, dominants introduced from California. The single remaining clump of *Stipa viridula* was disturbed by rodents and died later, leaving only *Andropogon nutans* and *A. scoparius* as survivors of the first season. Among these the mortality was very high; the leaf-tips of many plants were dead, while the best plants were only 4 to 6 inches tall. In the quadrats the same species did even more poorly, only five germinating. One of these died by June 2, while all of the others, after a period of leaf-rolling, wilting, and progressive drying of the leaves, succumbed by the middle of July or not long afterwards.

Sods of *Agropyrum glaucum*, *Andropogon scoparius*, *Bouteloua racemosa*, *Elymus canadensis*, *Koeleria cristata*, and *Stipa spartea* were transplanted from high prairie to gravel-knoll on April 20. *Andropogon furcatus*, *A. nutans*, *Poa pratensis*, *Panicum virgatum*, and *Spartina cynosuroides* were also trans-

planted here from the low prairie. Duplicate and often triplicate blocks of sod were used. One lot of each was watered thoroughly at two or three of the most critical periods during the summer. On June 15, none of the sods having been watered since transplanting, *Andropogon furcatus* and *Panicum* were badly wilted and the leaves on *Andropogon* were rolled, while both *Koeleria* and *Stipa* had blossomed earlier than elsewhere and the plants were drying at the base. Two weeks later, no rain having occurred until the 25th, all of the unwatered plants had either ripened seeds and were drying (*Koeleria, Poa, Stipa*), or had revived as a result of the rains, but were again in a wilted state. During August, one sod of *Poa* and another of *Andropogon scoparius* died, while the unwatered *Agropyrum, Andropogon furcatus* and another *A. scoparius* were nearly dead. The plants with a rather shallow root habit, viz, *Koeleria, Stipa,* and *Elymus,* suffered less, probably because they could compete more successfully with the gramas for water in the surface soil. However, *Bouteloua racemosa* and even *Spartina* survived in fair condition, although dwarfed. In addition to the three early bloomers already mentioned, *Elymus* and *Agropyrum* were the only ones that flowered. The ultimate fate of these species is indicated later (p. 83). The low chresard, or its entire absence during certain periods of drought, is shown in table 12.

Low-prairie Station.

Character.

This station was located on a level tract at the foot of the hill about 60 feet below the high-prairie and gravel-knoll stations and only a quarter of a mile southward (plate 5B). The soil is a fertile, dark-colored silt loam of the Wabash series. It is very fine in texture, being composed mostly of silt and clay (tables 13 and 14), and with the Truog test showed no trace of acidity. The greater amount of volatile matter and the greater nitrogen-content at all depths than in soil from the upland indicate more favorable conditions for plant growth.

Table 13.—*Mechanical analysis of soil from lowland cultivated area.*

Depth of sample (feet).	Coarse gravel.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.	Moisture equivalent.
0.0 to 0.5....	0.1	0.4	2.2	1.8	5.0	25.0	41.3	24.3	27.7
0.5 to 1.0 ft..	0.3	0.7	2.1	2.2	5.0	25.4	38.8	25.8	27.9
1 to 2.......	0.2	0.3	1.3	1.5	3.7	21.4	40.8	31.0	30.6
2 to 3.......	0.0	0.1	0.4	0.5	1.7	19.2	43.4	34.7	32.9

Table 14.—*Chemical analysis of soil from lowland cultivated area.*

Depth of sample (feet).	Insoluble residue.	Soluble salts.	Volatile matter.	Iron and aluminium oxids.	Calcium oxid.	Magnesium oxid.	Phosphorus pentoxid.	Nitrogen.
0.0 to 0.5..	79.34	12.96	7.70	9.57	0.68	0.75	0.13	0.218
0.5 to 1...	79.63	13.66	6.71	10.27	0.63	0.77	0.10	0.187
1 to 2.....	78.11	15.83	6.06	12.11	0.64	1.01	0.08	0.135
2 to 3.....	74.78	19.82	5.40	15.20	0.76	1.27	0.09	0.082

Moreover, the chresard is constantly greater than on the high prairie, though the area is well-drained and the soil is never waterlogged.

TABLE 15.—*Holard in excess of hygroscopic coefficient.*

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 10.....	28.7	22.3	21.8	18.7	18.8
Apr. 21.....	26.1	....	22.1	....	....
May 5.....	33.1	25.6	23.9	....	....
June 9.....	25.7	24.0	....	....	....
June 16.....	13.6	16.6	19.5	26.4	....
June 23.....	9.3	11.5	20.4	....	....
July 14.....	27.4	21.1	17.0	19.5	22.7
July 28.....	17.6	12.5	15.7	....	....
Aug. 5.....	2.3	8.2	11.5	12.0	23.6
Aug. 12.....	15.4	12.4	11.8	....	....
Aug. 19.....	21.8	8.8	10.1	....	....
Aug. 31.....	Continued heavy rains; no samples taken.				
Hygroscopic coefficient.	11.8	11.1	10.3	10.2	11.9

The low-prairie area is dominated by a few species less xerophytic than those occurring on the high prairie. Many of the species of the high prairie are absent, but are replaced in part by others of a more mesophytic kind. The dominant grasses are *Andropogon furcatus*, *Panicum virgatum*, *Andropogon nutans*, and *Spartina cynosuroides*, each of which often covers small areas with a pure or nearly pure growth. *Poa pratensis* is also very important, but is overtopped by the taller grasses, which reach a height of 5 or 6 feet (plate 6A). Characteristic forbs are *Solidago canadensis*, *S. rigida*, *Glycyrrhiza lepidota*, *Aster multiflorus*, *A. salicifolius*, *Physalis heterophylla*, *Polygonum muhlenbergi*, *Artemisia gnaphalodes*, *Achillea millefolium*, and *Callirrhoe alcaeoides*. The rank growth forms a dense cover and makes ecesis in the area very difficult. Bisects show that the plants are rooted deeply, most of them reaching depths of 5 to 12 feet. Root-layers at 3 and 5 feet are quite as distinct as those on the high prairie.

BEHAVIOR.

Surface sowings of eight species were made on April 10. Two failed to germinate, while *Bouteloua gracilis* germinated but soon died. By June 15 all were very delicate and much attenuated, owing to the low light intensity. A month later *Liatris punctata* had been shaded out and the others were slender and pale in color. *Stipa viridula* and *Andropogon scoparius* died later, leaving attenuated individuals of *A. nutans* and *Koeleria* surviving the first season. *Koeleria* had disappeared by the following spring, but *A. nutans* made a good growth and merged into the native sod. The light intensity under the cover of tall-grasses was so reduced as to constitute the major factor in competition, in view of the high holard. On June 14, 1922, in a portion of the prairie burned over the preceding spring, the light intensity under vegetation of average density and with an average height of 12 inches, was only 6 per cent. Some seedlings were growing in even deeper shade. By July 25 the average had dropped to 3.5 per cent; under a thin cover it was 12 per cent, but where the vegetation was very dense, only 1.5.

Seeds planted in the trench at the same time did somewhat better. Although three species failed of germination, all of the others, viz, *Andropogon nutans*, *Bouteloua hirsuta*, *Elymus canadensis*, and *Stipa viridula*, came through the season, although somewhat blanched and attenuated. Thus, *A. nutans* had reached a height of 7 to 8 inches as compared with a growth of 5 or 6 inches on the high prairie. Light in the trench in June varied from 5 to 10 per cent near the edge to 50 or 60 per cent in the center. By late July this was reduced to 4.5 to 16 per cent, even at 4 inches above the surface. Of the eleven species sown in denuded quadrats, all germinated, and all but one, *Stipa coronata*, came through the season in excellent condition. In fact, except for *Stipa setigera*, which was winterkilled, all became established. The marked development shows the possibilities of growth in this habitat when sufficient light is available. Little difference was apparent between the earlier and later sowings.

A comparison of growth in the denuded quadrats of the prairie and in the adjoining cultivated area is of interest. Both were seeded on the same dates, weeds being kept out of both areas. The native vegetation in the field was consequently free from any competition. *Aristida purpurea*, *Stipa comata*, *S. eminens*, and *S. setigera* failed to germinate, as did also the sowing of *Andropogon nutans*, *A. scoparius*, and *Koeleria cristata* made on April 9. All others made an excellent growth, even exceeding that in the quadrats. For example, the height in inches attained by August 30 by typical representatives in field and grassland respectively were: *Stipa viridula*, 20 and 5 to 7; *Koeleria cristata*, 3 to 4 and 2 to 3; *Elymus canadensis*, 14 to 16 and 7 to 11. Moreover, the species in the cultivated area were more heavily tillered and three, *Andropogon nutans*, *A. scoparius*, and *Elymus*, came into blossom in September. The root systems were well developed; the roots of *Elymus* reached a maximum depth of 4 feet and those of *Andropogon scoparius* were abundant to 3 feet, while some extended to 4.5 feet. The roots appeared finer than on older plants and were not so well-branched near the tips. The ample water-content of the fertile soil in the cultivated area, which was similar to that on low prairie, together with the lack of competition, accounts for the excellent growth.

Blocks of sods of the same species used on the gravel-knoll (except *Andropogon nutans*) and secured from the same sources were transplanted into low prairie from March 22 to April 24. *Bulbilis dactyloides* from overgrazed low prairie, *Distichlis* from salt-flat, and *Bouteloua gracilis* from gravel-knoll were also included. The prairie had been mown the preceding year. During the first season all of the plants flourished, including the short-grasses, *Bulbilis* and *Bouteloua gracilis*. The former produced stolons abundantly, but none were able to become rooted. Because of light conditions, the height growth of the shorter grasses was somewhat emphasized, while that of the taller species was quite normal for lowland. All the transplants flowered the first season, except *Spartina*. The effect of a reserve food-supply in the roots and rhizomes is shown by comparing a single season's growth of *Andropogon nutans* from a block of sod in the low prairie and from seed sown in the lower cultivated plats (plate 8A).

Salt-flat Station.

Character.

This station is located on a level tract of land just below and only 200 feet south of the low prairie. Owing to a small percentage of sodium chloride which

has deflocculated the clay (table 16), it is of a very different consistency from that of the low prairie (Hall, 1920: 283). Moreover, the adsorption of the Na ion in part has left the soil in a slightly acid condition, according to Truog's test.

TABLE 16.—*Acidity and salt-content at salt-flat station.*

Depth of sample.	Acidity.[1]	Total soluble salts.[2]		Chlorides.	
		p. ct.	p. p. m.	p. ct.	p. p. m.
0.0 to 0.5 foot.	Slight......	0.17	1,700	0.06	600
0.5 to 1.0 foot.	Very slight.	1.14	11,400	.18	1,800
1 to 2 feet....	...Do......	.46	4,600	.10	1,000
2 to 3 feet....	...Do......	.50	5,000	.12	1,200
3 to 4 feet....	...Do......	.64	6,400	.15	1,500

[1] Neutral to litmus in water-extract. [2] No carbonates were present.

The above conditions, as the holard is very similar to that in the low prairie, have greatly affected the type of vegetation. This consists of an open growth of salt-grass, *Distichlis spicata,* which is frequently mixed with a sparse growth of *Agropyrum pseudorepens* (plate 6B). In places occur scattered plants of *Poa pratensis;* other species, especially of forbs, are practically excluded. *Agropyrum* is much dwarfed, and with *Distichlis* forms a layer seldom exceeding 5 to 8 inches in height. The sparse flower-stalks are only 8 or 10 inches high, and consequently light plays a minor rôle in deciding the fate of transplants.

BEHAVIOR.

The same species as in the case of the low prairie and from the same sources as before, were transplanted into the salt-flats, with the exception of *Bulbilis. Andropogon furcatus, A. scoparius,* and *Panicum virgatum* had been transplanted during the spring of 1919. The first season they made a poor growth and none put forth flower-stalks; from the outset in 1920, *Stipa* appeared yellow and dwarfed. All of the others suffered more or less severely during the summer drought. Late in June nearly all showed more or less wilting and some yellowing. In July the ground was cracked on one or more sides of the blocks of sods, a phenomenon due to local soil texture and one which did not occur elsewhere, even in the dry soils at Burlington. However, none of the transplants died. Compared with their growth in the adjoining low prairie, nearly all were greatly dwarfed and lacked vigor and but 6 of the 13 species blossomed. These were *Agropyrum, Distichlis, Bouteloua gracilis, Elymus, Koeleria,* and *Stipa.* The flower-stalks were usually short and the inflorescence smaller than normal.

SWAMP STATION.

CHARACTER.

The swamp station is located in the valley at the foot of a hill 0.25 mile north of the high-prairie station. During 1920 water stood above the soil-

level throughout April, May, and most of June. For the remainder of the season the soil was saturated at nearly all times to near the surface. The vegetation consisted chiefly of a rank growth of *Spartina cynosuroides*, with *Scirpus atrovirens* and *Heleocharis palustris*. *Phalaris arundinacea* and relict *Typha latifolia*, with several species of *Juncus* and *Carex*, played a minor rôle. Adjoining the wettest area and making the transition to the grassland was a zone of almost pure *Poa pratensis*. Sods were transplanted into both areas. In the latter the water stood above the surface during April and May, while throughout much of the remainder of the season the soil was saturated or nearly so almost to the surface. Vegetation in both areas grew rank, but aeration was obviously a factor of equal or greater importance than light.

Behavior.

Sods of the same species used on the low prairie were placed in the wettest portion of the swamp and in the adjoining *Poa* zone on April 24. Water stood on the surface of the swamp until after June 15. By June 2, *Andropogon scoparius* and *Bouteloua gracilis* had died, and the leaf-tips were dead on *A. furcatus*, *Elymus*, and *Stipa*, while *Koeleria*, which was heading out at 4 to 8 inches high, had most of its leaves dead. *Spartina* and *Panicum* were thriving. By the middle of June the whole area was badly overgrown. *Heleocharis* had reached a height of 20 and *Scirpus atrovirens* 30 inches, while both *Poa* and *Spartina* overtopped all the transplants. Light values ranged from 2 to 10 per cent. *Bouteloua racemosa* had died and *Stipa* was nearly dead. The basal leaves on *Agropyrum* and *Elymus* had died, on the latter to a height of 9 inches, and *Distichlis* was much attenuated. The flower-stalks of *Koeleria* had rotted off at the base and only a few green leaves remained. *Koeleria*, *Stipa*, *A. furcatus*, and *A. nutans* completed the mortality list for the first season. *Spartina* had flower-stalks 5 feet tall. A few poor, slender plants of *Agropyrum*, *Distichlis*, *Poa*, and better ones of *Panicum* survived. The stems of *Elymus* rotted off near the ground, but new shoots came out from the base. *Panicum* did not seed. The other survivors, except *Spartina*, had gone through a period of anthesis earlier in the season.

Aside from a deficit of oxygen, low light intensities must be considered in accounting for these results. During July and August a dense growth of *Spartina*, *Scirpus*, *Phalaris*, etc., to a height of 4 feet or more so completely overshadowed the transplants that they were found with difficulty, and light values ranged between 1.8 and 7.5 per cent. Transplants in the *Poa* zone grew under slightly less unfavorable conditions in regard to both deficient aeration and reduced light. However, *Andropogon scoparius* and *A. nutans* both died in May and *Koeleria* and *Stipa* in July. Some of the other species had dead basal leaves and were more or less attenuated. All of the survivors except *A. scoparius*, *A. furcatus*, *Bouteloua gracilis*, and *B. racemosa* produced seed.

Sods of *Stipa setigera* and *S. eminens* from California were transplanted to both high and low prairie on April 27. They were watered from time to time as necessary. During May and early June all showed slight to fair growth, but by July 15 three had died at each station and the others were growing poorly. All had died on the high prairie by August 9, while only one of each species survived on the lowland. The leaves on these did not exceed 2 or 3 inches in

height. They remained alive until fall, when they were winterkilled. Sods of several species from Arizona were transplanted into high prairie on June 2 and were also watered from time to time. By June 15 some plants showed a new growth, but a month later half of them were dead and the others were doing poorly. These died during August, with the exception of a single *Bouteloua*, which produced a flower-stalk 20 inches high; however, this plant was winterkilled.

Summary.

Experiments.

A summary of the planting experiments is given in table 17. Omitting the data from Colorado Springs, where the plants were watered, the percentage of germination was greatest at Nebraska City and in the low prairie at Lincoln, as was also that of establishment, if the cultivated area is omitted. Establishment was lowest, 15 per cent, on the gravel-knoll. Of the species which frequently failed to germinate, *Aristida* failed at 6 places of planting, *Bouteloua hirsuta*, *B. gracilis*, *Koeleria*, and *Liatris* at 2 or 3 each, and *Andropogon scoparius* at 1. *Andropogon nutans* grew in 9 of the 10 places sown; *A. scoparius*, *Elymus*, and *B. hirsuta* in 6, while *Koeleria* and *Stipa viridula* grew in 4 of 5. In general, the percentage of germination, as well as that of establishment, increased from surface to trench to quadrat, and inversely with competition for water and light.

Table 17.—*Summary of planting experiments, 1920.*

Method of planting.	P. ct. of species germinating.					P. ct. of germinated species established.				
	Gravel-knoll.	Low prairie.	Cultivated land.	Nebraska City.	Colorado Springs.	Gravel-knoll.	Low prairie.	Cultivated land.	Nebraska City.	Colorado Springs.
Surface	..	75	..	80	..	..	33	..	50	..
Trench	71	57	67	100	..	30	100	100	60	..
Denuded quadrat	71	100	..	100	56	0	91	..	100	80
Average	71	77	67	93	56	15	75	100	70	80

Including with these data those from the high prairie at Lincoln, Phillipsburg, and Burlington, and arranging the stations in order of the average percentage of germination under the different methods of sowing, the sequence is that shown in column 1 of table 18. Column 2 gives the arrangement based on the percentage of the germinated species that became established, the low-prairie station ranking ahead of Nebraska City. The difference between the percentage of germination in high and low prairie is much less than the difference in that of establishment. The use of the most favorable method of planting, i. e., the denuded quadrat, gives practically the same sequence of stations.

TABLE 18.—*Comparison of germination and growth at all stations, 1920.*

Average per cent of germination.		Average per cent of establishment.		Per cent of establishment in denuded quadrats.	
Nebraska City	93	Low prairie	75	Nebraska City	100
High prairie, Lincoln	86	Nebraska City	70	Low prairie	91
Phillipsburg	80	High prairie	42	High prairie	80
Low prairie, Lincoln	77	Phillipsburg	33	Phillipsburg	67
Gravel-knoll, Lincoln	71	Burlington	25	Burlington	43
Burlington	38	Gravel-knoll	15	Gravel-knoll	0

In accounting for the above results, it remains only to compare the habitats at Nebraska City, low prairie, and gravel-knoll a little more fully. Those of the high prairie (Lincoln), Phillipsburg, and Burlington have already been shown to decrease in all conditions favorable for plant growth in the order mentioned.

PHYSICAL FACTORS.

A comparison of the holard at the gravel-knoll and Burlington stations shows that it is not greatly different, both very frequently falling to the hygroscopic coefficient (tables 12 and 6). In the first 6 inches especially it is often reduced by surface evaporation to even a lower point. The erosion of the soil about the seedlings was often pronounced on the gravel-knoll and in this respect growth conditions were less favorable than at Burlington. The cover of short-grasses on both areas indicates xerophytic conditions, the vegetation often drying and turning brown late in July or in August. The chresard was continuously higher on low than on high prairie, a difference of 5 or 10 per cent in favor of the former not being unusual. The low prairie was also better supplied with water than the Nebraska City station, though the hygroscopic coefficient was at no time reached in either habitat, a margin of 3 to 10 per cent or more at all depths usually being present. The average daily evaporation was also slightly less in the low prairie, Nebraska City being intermediate between the low and high prairie stations at Lincoln (fig. 19).

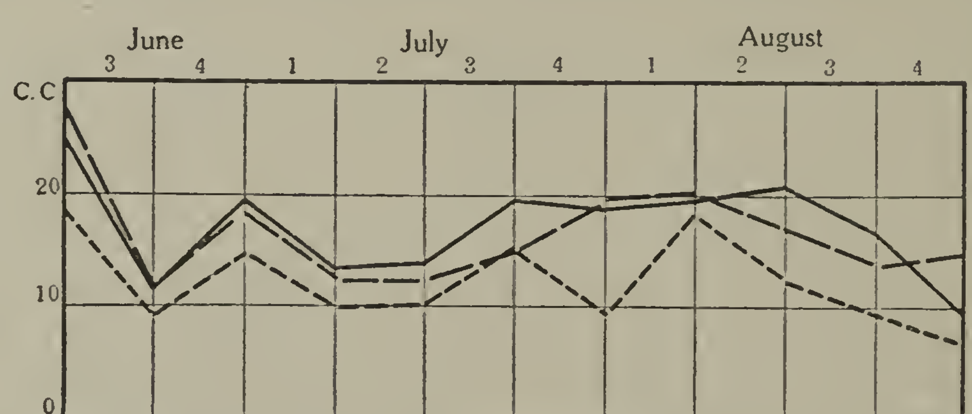

FIG. 19.—Average daily evaporation, high prairie (solid line), and low prairie, Lincoln (short broken lines), and Nebraska City (long broken lines), 1920.

However, a comparison of the average weekly humidity at these three stations shows this to be much higher at Nebraska City (68 to 82 per cent) than on the low prairie (57 to 79 per cent), the high prairie being lowest of all (58 to 73 per cent). The average weekly humidity at the three stations was

73.8, 71.9, and 65.4 respectively from June 3 to August 26. This factor seems sufficient to account for Nebraska City exceeding the low-prairie station both in per cent of germination and of establishment in denuded quadrats.

In summary, two sod transplants died from drought on the gravel-knoll. All showed repeated rolling and dying back of the leaves, including those watered from time to time, and the five which blossomed did so earlier than elsewhere. Drying at the base was often quite as pronounced as at Burlington. All of the transplants flourished on the low prairie and all but *Spartina* blossomed. On the salt-flats the transplants suffered more or less severely during drought, as shown by the wilting and yellowing of leaves. None died, but all were considerably dwarfed. The flower-stalks were short on the species that blossomed and the inflorescence smaller than normal. The sods in the swamp suffered from deficient aeration especially and also from deficient light. Five high-prairie species and two from the low prairie died. All but *Spartina* and *Panicum virgatum* showed the effects of deficient aeration, the basal leaves of several plants dying and the flower-stalks rotting off near the base. Six of the 13 produced seed, some on much abbreviated flower-stalks. Sods in the *Poa* zone of the swamp did somewhat better, only three high-prairie and one low-prairie species succumbing; two other high-prairie species failed to flower. Nearly all showed the effects of deficient aeration and shade, but to a less degree than those in the swamp. The transplants at Colorado Springs were made late in the season (June 9) and watered at intervals; all survived, but none made a good growth.

Experiments During 1918 and 1919.

Season of 1918.

Some preliminary experiments were conducted during 1918 and 1919, and an account of the results seems desirable for the sake of completeness. On April 6, seeds of the following species were sown in 4-inch pots in rich loam soil in the greenhouse: *Agropyrum glaucum*, *Andropogon furcatus*, *A. nutans*, *A. scoparius*, *Aristida oligantha*, *Bouteloua hirsuta*, and *Sporobolus asper*. When the roots had reached a depth of 3 to 5 inches and the plants were well established, the latter were transferred to trenches 8 inches wide and 6 inches deep. This was done on April 26 in both gravel-knoll and high prairie, 4 to 14 pots of each species being transplanted at each station. They were watered from time to time until June 1, when they were finally weeded and given no further attention until late in September. On October 25 to 27 the plants were counted, the roots excavated, and measurements taken. The summer was exceedingly dry and only one plant, *Sporobolus*, survived on the gravel-knoll. In the high prairie all of the *Aristidas* died, all but one of *Agropyrum*, and over half of *Bouteloua* and *Sporobolus*, while only the three species of *Andropogon* came through with small mortality.

Bouteloua hirsuta had reached an average height of 6.5 inches and most of the plants had seeded. The bulk of the root system (plate 8B) was in the first 8 inches of soil, although some roots penetrated considerably deeper. *Andropogon furcatus* attained a height of 5 or 6 inches and the coarse roots were traced well below the 18-inch level; *A. scoparius* was 8 to 10 inches tall; the central plant in plate 9A shows the major portion of the root system, the roots being much finer and more abundant than in the preceding species.

A. nutans grew to a height of 7 or 8 inches (plate 9A). The largest of the three survivors of *Sporobolus asper* reached a height of 10 inches, the plants were in seed, and the roots penetrated more than 15 inches, the lateral spread reaching distances of 8 to 10.5 inches. The difficulty of extracting the entire root system in grassland has already been mentioned. Because of competition the shoot growth was less than in cultivated soil, and it seems probable that the root system was also shortened. These root systems, which were only partially recovered, afford a striking contrast to those of similar species of a single year's growth in cultivated soil (p. 35 and 36).

Season of 1919.

During 1919, *Andropogon furcatus* was sown in quadrats on May 10 and again on June 15 in high prairie, low prairie, gravel-knoll, and in the lower cultivated plats. Those on the high prairie which were watered on May 28 at the same time as the others, did very well, and little difference was noted between the two plantings. In June 1920, both quadrats contained plants 6 to 8 inches tall, which reached 7 to 10 inches by fall, but no flower-stalks appeared. A good sod, almost merging into the native prairie, was developed during 1921, but no species flowered. By June 1922, some invasion had occurred, and later in the season, as well as in 1923, flower-stalks were produced, although rather sparsely. Those on the low prairie made a better growth the first season, but, because of the plowing of the area, were transplanted to salt-flat and the new low-prairie station the following spring. Both lots continued to thrive (pp. 44 and 45). Plantings of this same species on the gravel-knoll died the first season or the following winter. Those made in the lower cultivated plats did best of all. The roots of the plants were excavated on August 26, when they had a working depth of 2 feet and a maximum depth of over 3 feet (plate 9B). A few stalks flowered and set seed. The vegetative growth by August of the second season was 2 feet high. Flower-stalks, some of which were 44 inches tall, occurred in abundance and good seed was developed.

When about 3 weeks old, duplicate seedlings of *Aristida purpurea*, *Stipa viridula*, and *Elymus canadensis* were transplanted in the usual way on May 5, into high and low prairie, gravel-knoll, and upland and lowland cultivated areas. *Bouteloua racemosa* was also included in the last two stations. All of those on the gravel-knoll died before the end of August, after repeated wilting and drying throughout the summer. Those on the low prairie grew well until fall, but were plowed up the following spring. On the high prairie all lived through the first season, but did not survive the winter.

Aristida and *Stipa* both died on the cultivated upland, while *Bouteloua* and *Elymus* made an excellent growth and were in full bloom August 1. By August 15, *Bouteloua* had reached a height of 23 inches (plate 4B). Clumps of *Elymus* 1.5 to 2 inches in diameter at the base were common, and as many as 66 stalks were counted in a single clump. The dense root system (plate 4A) reached a depth of 2 feet and a maximum lateral spread of 22 inches.

All the plants grew very well in the lower cultivated plots, except *Aristida*, which did rather poorly. *Bouteloua* came into full bloom late in August, after making an excellent vegetative growth, and it matured seed abundantly. *Elymus* also blossomed, and by August 9 of the second season had flower-

stalks 58 inches tall with very large spikes. *Stipa viridula* made an excellent growth, but did not seed until the next year. By August 9, 1920, the seed was ripening on flower-stalks over 5 feet tall and in spikes 14 inches in length. The root system at this time had reached a depth of over 5 feet and had a lateral spread of 18 to 20 inches near the surface. Roots were very abundant to 2 feet. In fact, the fine growth and great size attained by native species under favorable conditions emphasize the controlling effects of competition in the native grassland.

Sod Transplants.

Gravel-knoll.

The following sods were transplanted to the gravel-knoll during the spring of 1919: *Agropyrum glaucum, Andropogon furcatus, Bulbilis dactyloides, Elymus canadensis, Koeleria cristata,* and *Panicum virgatum.* They were watered a few times until established. *Agropyrum, Bulbilis, Elymus,* and *Koeleria* all blossomed somewhat earlier than elsewhere, the flower-stalks being somewhat dwarfed. During July all dried out badly, *A. furcatus* and *Koeleria* dying by the end of the season. Four sandhill dominants, *Andropogon halli, Calamovilfa longifolia, Muhlenbergia pungens,* and *Sporobolus cryptandrus,* were secured from the extra-regional sandhills near Central City, Nebraska, and transplanted into the high prairie on June 9. Great difficulty was encountered in holding the sand in place about the root systems. The new shoot growth was clipped back as usual to lessen transpiration, but in spite of repeated watering, none survived.

Table 19.—*Holard in excess of hygroscopic coefficient on the gravel-knoll, 1919.*

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 28	24.0	25.3	20.5	19.0	12.0
May 10	7.3	5.6	7.1	7.9	1.1
May 27	1.0	1.7	3.6	....	....
June 16	7.0	6.6	....	....	....
July 1	0.2	0.1	....	....	....
July 8	−1.1	−0.4	2.4	3.5	....
July 14	−1.7	−0.1	....	....	....
July 28	1.6	1.7	6.7	11.4	7.1
Aug. 26	−0.7	6.6	7.2	6.7	7.1
Sept. 6	−0.9	−0.5	0.4	4.1	8.3
Hygroscopic coefficient	5.2	4.9	3.1	2.8	7.4

An examination of the rainfall records shows that while May and June had ample rainfall, July was extremely dry. The total rainfall was only 0.38 inch (normal 3.83 inches), 0.30 inch of which fell on the last day of the month. The rainfall for August was also an inch below normal. The low holard of the gravelly soil in which the plants were growing is shown in table 19. On July 14 the native grama grasses (*Bouteloua gracilis* and *B. hirsuta*) began to dry badly and two weeks later all were brown and cured on the ground.

During 1920, which was a more favorable season, *Agropyrum* produced a thin crop of flower-stalks 34 inches high, while *Bulbilis* flowered profusely and put forth numerous stolons 8 to 12 inches long, some of which rooted in the

grama sod. Only 2 stalks of *Elymus* about a foot tall were left; *Panicum* did poorly, reaching a height of but 12 to 14 inches. Undoubtedly by this time most of these species were rooted rather deeply in the clay subsoil at about 4 feet depth. In 1921, *Agropyrum* again blossomed, but not profusely, while *Bulbilis* seemed quite at home, blooming luxuriantly and extending its territory nearly a foot into bare areas. One of the two stems of *Elymus* put forth a flower-stalk at 18 inches height; *Panicum* remained dwarfed (13 inches) and did not blossom. During 1922 all made an excellent growth, except *Elymus*, which was winterkilled. As usual, *Agropyrum* blossomed early; *Bulbilis* had spread until it occupied nearly twice its original area, and *Panicum* flowered at 18 to 24 inches. All dried earlier in the late summer than elsewhere, owing to the severe drought in August. The next year was an excellent one for growth, and *Agropyrum* spread over 30 inches into the adjacent grassland, flowering profusely at 2.5 to 3 feet. *Bulbilis* spread even more widely than before, but the stolons rooted with difficulty in the heavy growth of grasses; it also flowered profusely. *Panicum* likewise increased its area slightly, but blossomed at a height of only 27 inches.

Low and High Prairie.

The same species, except for *Panicum* and *Andropogon furcatus*, but including *A. scoparius* and *Stipa spartea*, were transplanted to the low prairie during April and early May 1919. All flourished and bloomed profusely except *Stipa*. No further data were obtained, since this part of the prairie was broken the following spring. A similar lot of sods, with the addition of *Bouteloua gracilis* from the gravel-knoll and *Panicum, Poa, Andropogon*

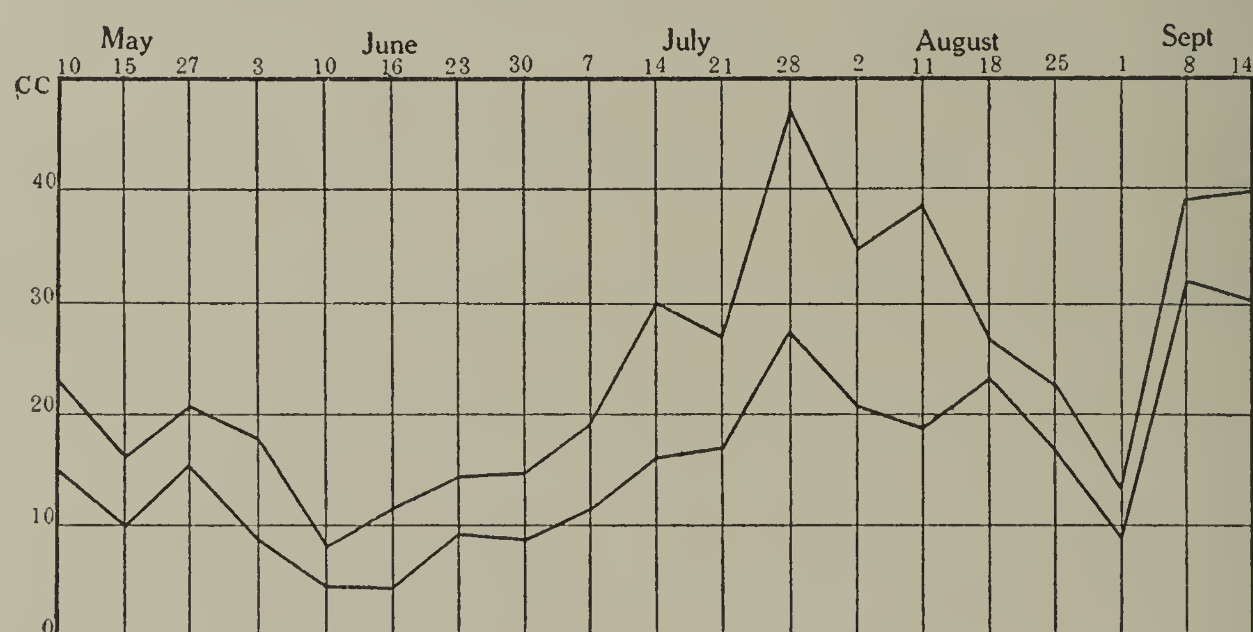

Fig. 20.—Average daily evaporation on high prairie (upper line) and low prairie (lower line), 1920.

furcatus, and *Spartina* from the low prairie, were transplanted to high prairie. Because of the severe drought during July, the transplants wilted somewhat and both the production and size of flower-stalks and inflorescence were reduced. The chresard on both high and low prairie is given in table 20.

The high evaporation rate (daily average 30 to 50 c. c.) on the high prairie during the drought period, and the relatively lower one on low prairie (15 to 28 c. c.), together with the evaporation throughout the season, are compared

in figure 20. Greater wind movement at the upper station was an important factor in causing the difference in evaporation, although humidity played a large share also. From July 7 to August 18 the average daily evaporation was 64 per cent greater at the upland station.

TABLE 20.—*Holard in excess of hygroscopic coefficient on high and low prairie at Lincoln, 1919.*

Date.	High prairie.					Low prairie.				
	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Apr. 28	18.5	22.2	19.1	13.8	11.4	24.4	26.5	....	....	16.1
May 5	19.8	18.2	15.6	9.8	14.2	26.1	17.3	16.1	17.5	19.5
May 27	8.2	13.7	11.2	....	....	8.8	17.8	16.4	....	....
June 16	16.6	16.6	....	....	....	24.5	18.6	....	....	....
July 1	11.5	10.0	9.5	9.9	10.0	11.7	11.1	17.1	17.1	18.5
July 8	2.3	5.3	9.2	10.7	9.2	5.4	5.7	16.8	17.1	20.6
July 14	0.0	3.5	5.2	....	....	4.4	5.6	9.6	....	....
July 28	−0.6	1.2	1.6	7.1	11.1	0.1	1.9	5.1	13.3	18.5
Aug. 11	4.4	2.0	2.0	3.3	7.0	6.8	3.6	5.9	8.1	18.1
Aug. 26	10.4	3.2	2.2	5.4	5.4	17.2	6.1	7.3	8.9	17.9
Sept. 6	1.2	3.3	3.4	5.6	8.3	−0.2	4.4	2.6	9.3	18.9
Sept. 26	14.5	15.0	5.2	2.6	5.7	17.2	15.2	5.8	10.0	16.2
Hygroscopic coefficient	9.5	8.7	8.6	7.1	6.2	11.8	11.1	10.3	10.2	11.9

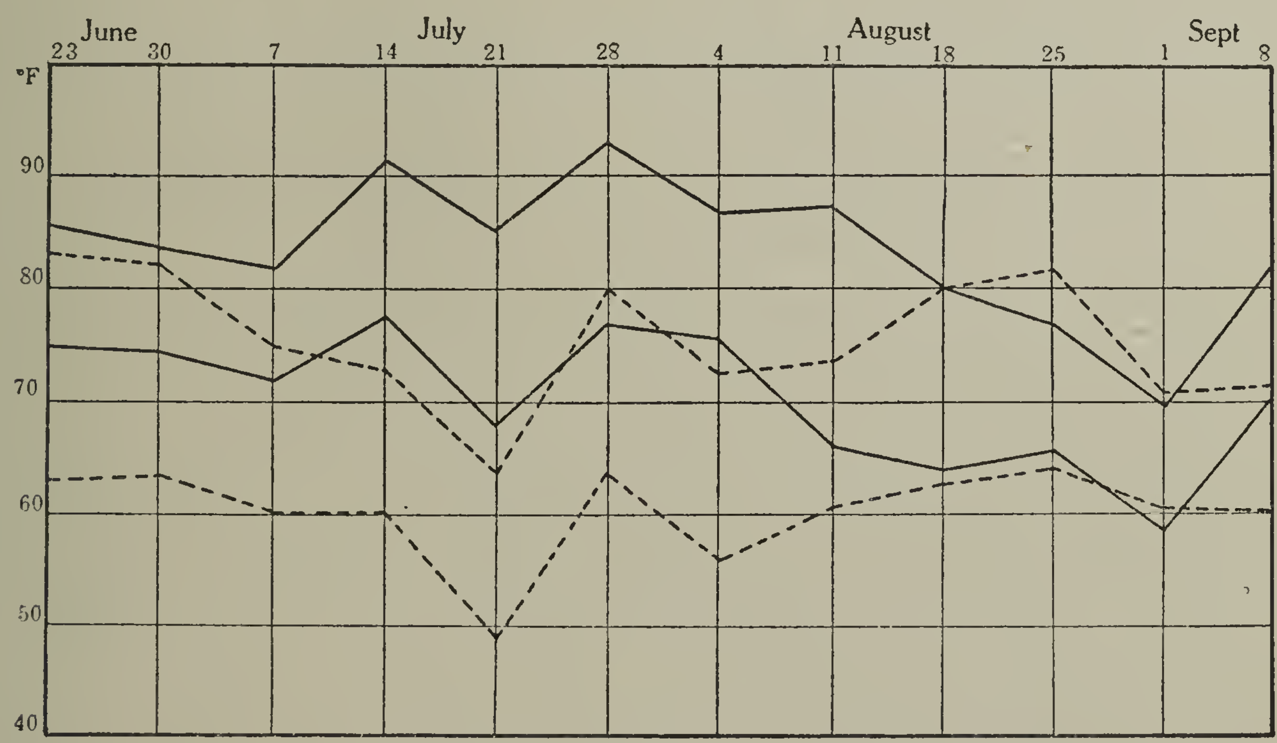

FIG. 21.—Average day and night temperature at Lincoln (solid lines), and Colorado Springs (broken lines), during 1919.

Thermograph records of soil temperature at the two stations at a depth of 6 inches show no marked differences. The daily range at the lowland station was usually 4° to 7° F.; in the drier soil of the upland station 4° to 12° F. The minimum soil temperatures were 2° or 3° F. lower at the former station and the maximum 3° to 9° F. higher on the upland. The soil temperatures varied from 53° F. (average 60° to 65° F.) late in May, to 85° F. (average 70° to 78° F.) in August. Except in early spring, when the low temperatures on the lower

wetter soil may retard growth, and the higher temperatures at all depths on the upland may facilitate absorption, it is not probable that the effects of temperature on the development of vegetation at the two stations are very different. A comparison of the two sets of thermograph records shows that differences of air-temperature greater than 5° F. are rare at the two stations. It seems certain that such small differences in temperature variations in the range of growth conditions (minimum 65° F. late in May, maximum 105° F. in July and August) would be almost negligible in the development of natural grassland. The average day and night temperatures throughout the season, together with those at the Colorado Springs station, are compared in figure 21 and the average daily evaporation rates at the same station in figure 22. Notwithstanding the adverse conditions, all the transplants, including *Spartina*, bloomed more or less profusely, with the exception of *Andropogon furcatus*, *Koeleria*, and *Stipa*.

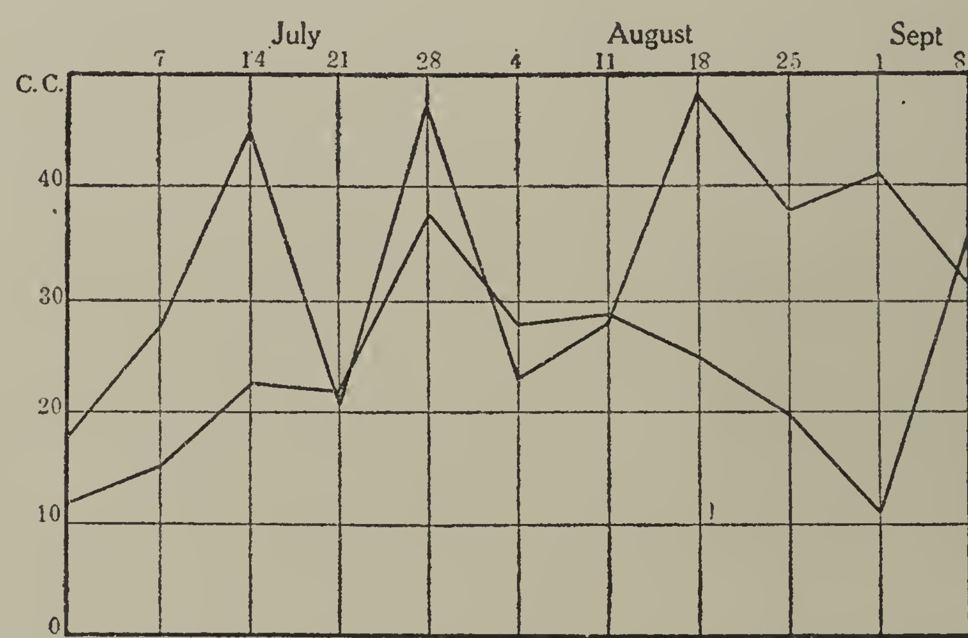

Fig. 22.—Average daily evaporation at Colorado Springs (upper line), and Lincoln (lower line), during 1919.

During 1920, all of the transplants did quite well, except two of the *Stipas* which were not well developed. *Bulbilis* made an excellent growth, blossoming profusely by the middle of June (plate 10A), and both *Panicum* and *Spartina* flowered abundantly at heights of 30 to 44 inches. In fact, *Andropogon scoparius* and *A. furcatus* were the only species that did not blossom, but they made a vegetative growth of 8 to 12 inches. By the following season, *Andropogon furcatus* had almost merged into the common sod. *Koeleria* was nearly all dead; two of the *Stipas* were behaving normally, while the other two did not blossom and were in very poor condition. *Elymus* was represented by only one or two stalks, but all of the other species were developing quite normally.

On August 23, when *Panicum virgatum* was blooming profusely with flower-stalks 3 to 4 feet tall, a trench was dug to a depth of 11 feet and the roots of this 3-year-old transplant examined. Below 3 feet the silt-loam soil became more sandy and below 6 feet it changed to a sandy gravel with many small rocks. It was quite moist at all depths. The roots penetrated to a maximum depth of 9.8 feet, and were fairly abundant to 7 feet. The general root habit and branching were about normal (Weaver, 1920), but the degree and extent of branching were considerably more pronounced than in the low prairie.

However, it did not approximate the remarkable network of branches displayed by this species in the drier soils at Burlington (fig. 32).

Spartina cynosuroides was also excavated from the same trench at this time. It had made a good growth, notwithstanding the rolling of leaves from time to time as a result of drought. Many leaves reached a height of 40 inches. It had increased its area about one-third by rhizome propagation, but the rootstocks had not developed many new shoots. Roots were abundant to 9 or 10 feet and were densely branched throughout, perhaps having a third more branches than those in the lowland, and branches were longer and rebranched to a greater degree than those growing in wetter soil. *Koeleria* and *Poa* died during the winter of 1921–22. The following summer all the rest, except *Andropogon scoparius*, made a good growth, and flowered rather profusely, except the very late bloomers, which were somewhat retarded by the late summer drought. *Panicum* extended its territory nearly 3 feet, but few of the others gained in area. During 1923 all did very well, owing to good growth conditions, *Andropogon furcatus* merging completely with the native sod. All flowered and set seed, the height of the inflorescence being about normal.

Mixed Prairie.

On June 19, 1919, the following sods from Lincoln were transplanted to the mixed-prairie station at Colorado Springs: *Agropyrum glaucum*, *Andropogon furcatus*, *Bulbilis dactyloides*, *Elymus canadensis* (2 sods), *Koeleria cristata* (3 sods), *Panicum virgatum*, *Poa pratensis*, and *Stipa spartea* (3 sods). Before planting, the hollow made for each sod was filled with water that was allowed to sink away before the sod was planted, tamped in place, and again watered. Owing to watering at 2-week intervals, all did fairly well the first season. In June 1920, cattle broke in and closely grazed the entire fenced area. However, most of the sods lived throughout the season, but made a poor growth, *Bulbilis* and *Agropyrum* alone coming into blossom. One *Elymus* and one *Koeleria* died late in the summer. During 1921, perhaps as a result of repeated grazing, the remaining *Elymus* and the two remaining koelerias died, as did also one of the stipas; *Bulbilis* alone came into blossom. The area was grazed again in 1922. This repeated grazing, combined with drought, resulted in a very poor growth, *Poa* succumbing and *Bulbilis* alone blossoming. Because of further grazing in 1923, it was clearly evident that most of the plants (except *Bulbilis*) were rapidly losing ground, *Agropyrum*, *Panicum*, and *Andropogon furcatus* being represented by remnants only.

3. EXPERIMENTS DURING 1921.

PHYSICAL FACTORS.

Rainfall.

The season of 1921 at Lincoln was quite favorable as to precipitation. Rainfall for April, June, and July was slightly above normal, while August was slightly below normal, as was May also (fig. 9). An examination of the records shows that the showers were exceptionally well distributed, no marked drought periods occurring, and at no time did the vegetation become dry or brown, even on the gravel-knoll.

At Phillipsburg an excess of 0.14, 0.98, and 1.30 inches fell during April, May, and June respectively. The July precipitation was slightly above normal and that of August and September slightly below (fig. 15). A drought period occurred between June 9 and 28, during which time no efficient moisture fell. At Burlington the precipitation for April was nearly twice normal (and 0.86 inch more than at Lincoln). May fell 0.91 inch below normal; June was somewhat above (0.58 inch); July had less than half the usual amount (only 1.15 inches); August had an excess of 1.19 inches, but September a deficit of more than one-half the normal (fig. 16). No efficient rainfall occurred (i. e., showers of over 0.15 inch) between March 7 and April 15, April 17 and May 19, June 22 and July 4, and July 8 and August 7. By July 24

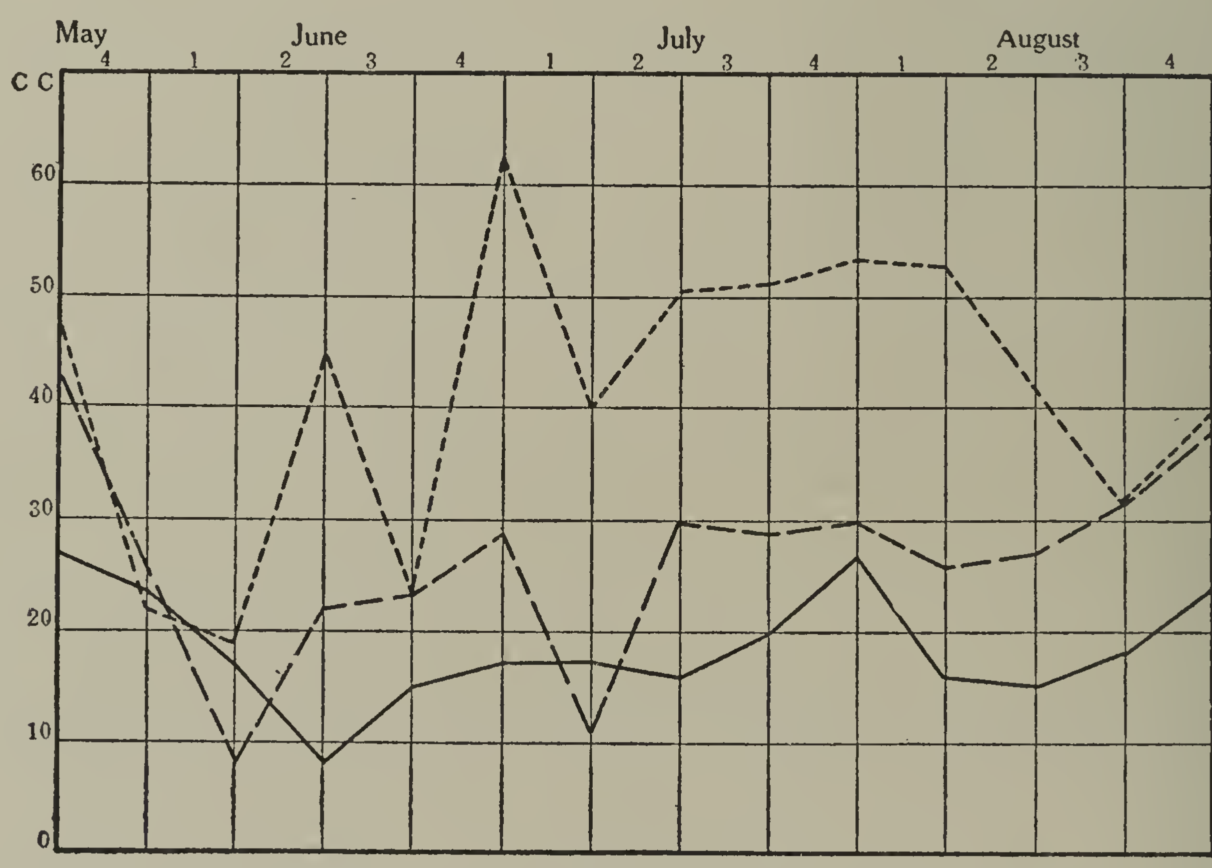

Fig. 23.—Average daily evaporation at Burlington (short broken lines), Phillipsburg (long broken lines), and Lincoln (solid line), 1921.

the short-grasses were about half-dried and brown, while two weeks later not only the grama and buffalo grasses were curled and brown, but the wheat-grass heads were dry as well.

Water Relations.

The above conditions were reflected in the holard at the several stations (table 22). At Lincoln, a margin of 5 per cent or more (usually 8 or 10)

existed at all times and at all depths to 4 feet. At Phillipsburg the echard was approached once in July and twice in August, actually reaching the danger-mark to a depth of 4 feet late in that month. Conditions at Burlington were, as usual, much worse. At no time was water available in the third

TABLE 21.—*Humidity at Lincoln and Burlington, 1921.*

For week ending—	Average day.		Average night.		Average daily.	
	Lincoln.	Burlington.	Lincoln.	Burlington.	Lincoln.	Burlington.
Apr. 21	53.9	....	64.7	....	59.3	....
Apr. 28	53.7	....	81.0	....	67.3	....
May 5	57.4	37.0	86.4	71.5	71.9	54.2
May 12	57.6	....	73.5	....	65.5	....
May 19	56.1	....	73.9	....	65.0	....
May 26	43.7	....	64.2	....	53.9	....
June 2	57.2	39.4	79.4	78.7	67.9	59.0
June 9	63.2	....	84.4	....	73.8	....
June 16	61.4	50.4	81.7	87.0	71.5	68.7
June 23	61.7	....	80.2	....	70.9	....
June 30	60.4	30.0	81.7	72.1	71.0	51.0
July 7	66.0	50.9	83.6	81.0	73.5	65.8
July 14	58.2	....	84.3	....	71.2	....
July 21	57.7	42.5	80.4	75.5	69.0	59.0
July 28	63.0	40.0	78.4	78.3	70.7	59.1
Aug. 4	66.7	38.4	85.1	72.6	75.9	55.5
Aug. 11	62.0	42.8	81.9	79.8	71.8	61.3
Aug. 18	65.3	49.3	83.4	83.6	74.3	66.4
Aug. 25	58.0	....	83.4	....	70.7	....
Sept. 1	62.0	....	86.4	....	74.2	....

or fourth foot, while after June 30 it was depleted repeatedly above the hardpan (at about 2 feet). A complete record of humidity was not obtained, but a comparison of the average daily humidity at Lincoln and Burlington at the several intervals (table 21) shows that without exception the air during the day at Burlington was 10 and often 30 per cent less humid than at Lincoln.

FIG. 24.—Average daily temperature at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1921.

Owing to the lower night temperatures at Burlington (altitude 4,160 feet), the humidity at this less critical period averaged only slightly lower than at the true-prairie station.

TABLE 22.—*Holard in excess of the hygroscopic coefficient at the several stations, 1921.*

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
LINCOLN, NEBRASKA.					
Apr. 9	20.2	17.9	13.7	13.3	12.5
May 18	18.0	19.7	16.7	15.0	14.5
May 25	6.2	13.2	....	....	....
June 1	7.9	10.3	....	....	....
June 7	23.0	18.6	14.9	14.5	17.2
June 22	8.8	14.1	15.1	....	....
June 29	7.0	8.8	11.8	15.2	....
July 13	13.4	20.1	10.4	....	....
July 20	21.0	18.5	12.7	13.1	16.8
July 28	7.5	7.3	....	....	....
Aug. 3	10.2	11.0	11.3	....	....
Aug. 10	16.4	17.9	12.0	12.1	26.8
Aug. 23	10.8	12.9	8.5	11.4	8.8
Aug. 31	8.5	7.0	5.1	....	....
Hygro. coeff.	9.5	8.7	8.6	7.1	6.2
PHILLIPSBURG, KANSAS.					
Apr. 28	15.8	14.5	11.4	5.9	2.3
May 19	16.8	13.0	9.8	6.4	0.7
May 25	12.2	10.9	....	....	....
June 9	19.8	15.8	13.9	14.5	13.0
June 22	5.3	8.6	10.8	11.7	9.3
July 19	1.6	2.2	....	....	....
July 21	8.2	3.3	3.9	4.6	....
July 25	1.6	2.0	0.9	2.7	4.9
Aug. 4	3.5	4.4	....	....	....
Aug. 9	0.1	0.8	0.6	2.1	2.1
Aug. 17	20.9	7.5	1.5	1.3	....
Aug. 30	−1.6	−0.4	−0.6	0.0	0.3
Hygro. coeff.	10.6	10.6	10.9	10.6	10.7
BURLINGTON, COLORADO.					
Apr. 30	9.6	10.7	8.6	0.0	1.3
May 20	6.4	5.6	4.7	−0.7	−2.2
June 10	10.3	0.0	0.7	−0.5	−0.6
June 30	−2.6	−1.6	−1.5	−1.0	−1.3
July 17	−1.0	−1.0	−3.6	....	....
July 24	−3.5	−2.2	−3.4	−1.8	−0.4
Aug. 8	2.0	−0.7	−2.1	−0.3	−1.0
Aug. 17	16.9	11.7	−2.4	−2.0	....
Aug. 29	−0.3	0.5	−2.1	−0.4	−1.0
Hygro. coeff.	10.9	10.9	12.2	12.0	11.4

The average daily evaporation at the several stations is shown in figure 23. The rather uniform rate at Lincoln (daily average 8 to 27 c. c.), as compared with the erratic and excessively high one at Burlington (18 to 62 c. c.), empha-

sizes the precarious conditions for plant growth at the latter station. Conditions at Phillipsburg were intermediate (8 to 43 c. c.).

Temperature.

The average daily air-temperature was in general lowest at Burlington, while that at Phillipsburg after the third week in June was somewhat higher than at Lincoln (fig. 24). During May and June, day temperatures were highest at Lincoln and lowest at Burlington, but after July 1 this was usually reversed. Night temperatures throughout the season were distinctly

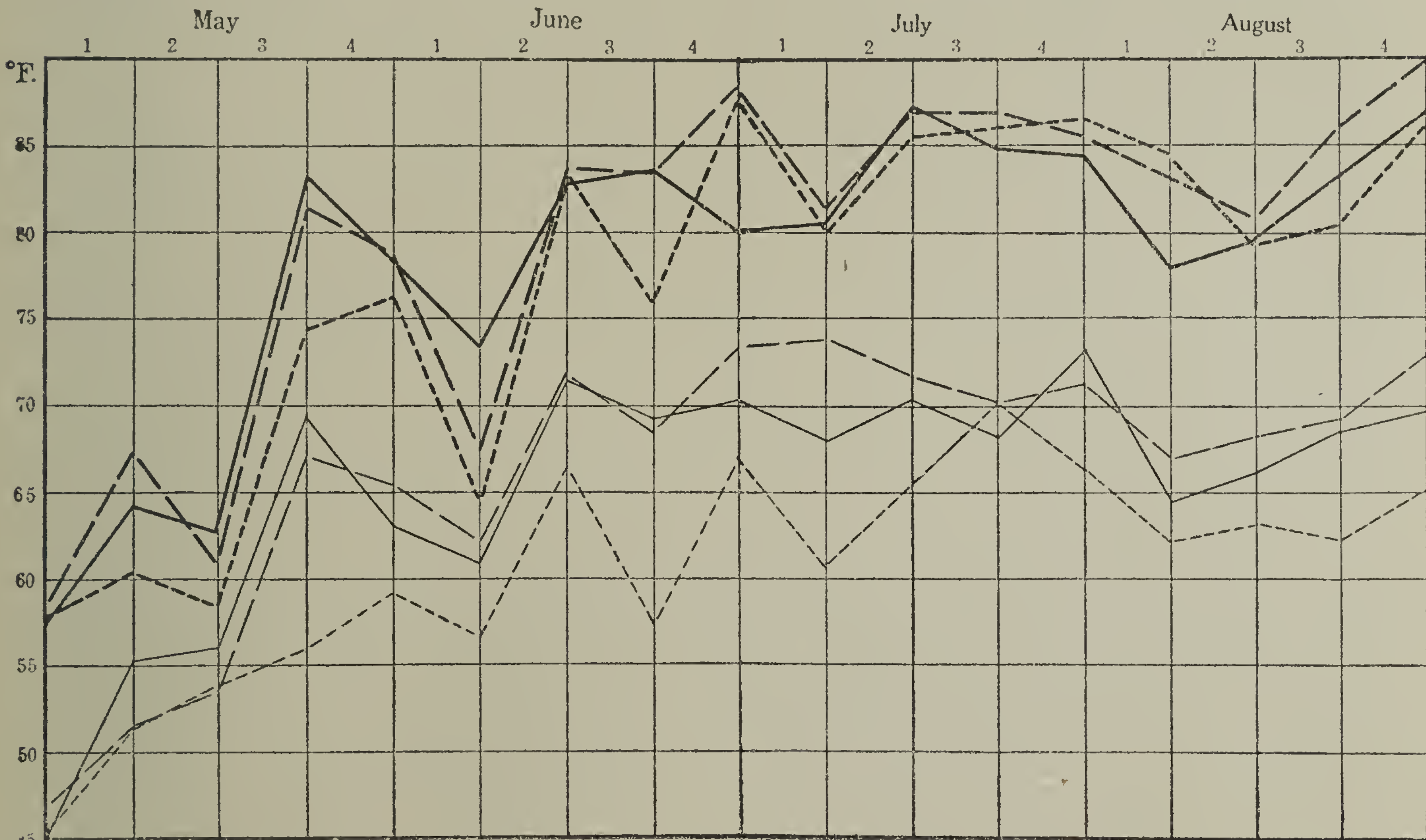

Fig. 25.—Average day (heavy lines) and night temperatures (light lines), at Lincoln (solid lines), Phillipsburg (long broken lines), and Burlington (short broken lines), 1921.

lower at Burlington by 5° to 10° F., those at the other stations being very similar. The soil-temperature at a depth of 3 inches was invariably lower at Burlington than at Phillipsburg. Later in the season soil-temperature was correlated with the holard, the soils becoming progressively drier and warmer. A series of readings in cropped areas (oat field) to a depth of 4 feet is instructive in this connection (table 23).

Table 23.—*Soil temperatures, 1921.*

Depth in feet.	April 28–30.			May 19–21.			June 9–10.			June 22.		June 30.
	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
0 to 0.5 . . .	15.4	24.0	12.0	21.0	20.0	22.2	22.5	21.4	19.8	21.2	23.2	29.2
0.5 to 1 . . .	13.0	23.1	11.0	19.0	17.8	15.0	21.8	20.2	18.8	21.1	22.4	26.1
1 to 2	12.0	15.0	10.5	13.4	16.4	14.0	20.2	18.8	16.8	20.1	21.5	23.9
2 to 3	12.0	14.0	10.5	13.1	15.0	12.4	18.6	17.2	15.8	18.8	21.2	21.8
3 to 4	10.8	12.0	10.0	12.0	13.5	11.8	17.8	16.0	15.0	17.4	20.5	20.0

Isolated readings at similar depths showed the temperature of the grassland soil (below the first foot) to be very similar to that in the cultivated areas.

To summarize; as during 1920, conditions for plant growth were much more favorable at Lincoln and least favorable at Burlington, while those at Phillipsburg were intermediate, holard and humidity being the controlling factors.

PLANTING RESULTS.

Surface Sowing.

Seeds of 14 species were sown on the surface of the high prairie at Lincoln on April 20. *Aristida purpurea*, *Elymus canadensis*, and *Lespedeza capitata* failed to germinate. *Bouteloua gracilis*, *Koeleria cristata*, *Liatris punctata*, and *Sporobolus asper* germinated rather abundantly, but died before the end of June, the seedlings being much attenuated. The light values were low; by May 5 they fallen to 16 to 27 per cent, as the prairie had not been mown the previous autumn. There was not only considerable dead grass, but the new growth was rank and flower-stalk production greater than usual. Before the end of July, *Bouteloua hirsuta*, *Bromus inermis* (which was badly eaten by grasshoppers), *Liatris scariosa*, and *Pinus ponderosa* were added to the mortality list. *Robinia pseudacacia* held out until August, as did also *Stipa viridula*. *Andropogon nutans* alone survived the season, making a fair growth 6 to 9 inches high and becoming indistinguishable from the native sod.

At Phillipsburg the surface plantings made on April 28 did very much better, 83 per cent living throughout the summer. After planting, showers were opportune at both stations, all 12 species germinating at Phillipsburg. Unquestionably the light relation was much more favorable at the latter station. Reduced light and surface drought were the chief factors to which plants gaining a foothold in climax grassland were subjected. The same species as those used at Phillipsburg, with the addition of *Sporobolus*, were sown on the surface at Burlington, April 30. None had germinated by May 20, and only 5 of the 13 germinated at all. These were *Bouteloua racemosa*, *B. gracilis*, *Bromus inermis*, and the two species of *Liatris*. All were found in greater or less abundance on June 10, but had disappeared by the 30th.

The fate of surface-sown plants of the preceding year is of interest. At Lincoln and Phillipsburg none survived the first season. By May of the second year at Burlington, *Bouteloua gracilis* had merged into the native sod. *Stipa viridula*, the other survivor, made a good growth (8 to 10 inches) and tillered heavily, standing out quite plainly in the short-grass turf. Its leaves were tightly rolled and somewhat wilted from time to time, and it did not produce flower-stalks. During 1922 it grew vigorously, but was much smaller than similar plants in denuded quadrats. By the end of the season it was clear that competition with the native short-grasses was too severe, *Stipa* rapidly losing ground. However, it held out through the very favorable season of 1923, being represented by only a few culms 6 to 8 inches high, while the leaves of grama were 6 inches tall all around it. It was clearly evident that it would soon lose in the unequal struggle.

Trench Sowing.

Although poor at all stations, the results from trench planting April 20 to 30 were best at Lincoln. Of 12 species used, all but *Pinus ponderosa* germi-

nated; *Elymus, Koeleria, Bromus,* and *Stipa viridula* succumbed before the end of June, the last two being badly eaten back by grasshoppers. The slender plants of *Lespedeza* and *Liatris punctata,* the latter reaching a height of 5 or 6 inches, died in August. *Andropogon nutans, B. hirsuta,* and *Sporobolus* came through in excellent shape, tillering heavily and forming a rather dense sod from 2 to 6 inches tall. *Bouteloua gracilis* was represented by remnants only, and *Liatris scariosa* by a dozen one-leaved slender plants.

In the trench at Phillipsburg, *Bouteloua racemosa, B. gracilis, B. hirsuta, Koeleria, Lespedeza, Liatris scariosa* and *punctata,* and *Pinus* failed to germinate, while *Bromus* and *Elymus* died in June and *Stipa viridula* in July. A single plant of *Robinia pseudacacia* with 5 leaves and a height of 4 inches lived through the summer but was winterkilled. The only species that became permanently established were *Andropogon nutans* and *Aristida purpurea;* the former was represented in late summer by 4 or 5 good clumps, 3 to10 inches tall. Of the same species sown in the trench at Burlington, *Bromus* and *Elymus* alone germinated, and very sparsely, but both died during the June drought.

The development of the plants grown in the 1920 trench at Lincoln was above the average. During 1921, *Andropogon nutans, A. scoparius, Bouteloua hirsuta,* and *B. racemosa* all made excellent growth. The boutelouas reached heights of 3 to 8 inches, and the andropogons of 5 to 10 inches, the latter forming a fairly dense sod. *Bouteloua gracilis* was represented by a single remnant, which was winterkilled. During 1922 the four remaining species made a fair growth, the boutelouas alone flowering and producing a single flower-stalk each. These grew well in 1923, though *Andropogon scoparius* and *Bouteloua racemosa* were quite sparse. The height growth ranged from 4 to 14 inches, but none had developed flower-stalks late in August.

At Phillipsburg, *Andropogon scoparius* and *A. nutans* alone survived the first season. During 1921 they flourished, forming dense bunches and reaching heights of 14 and 24 inches respectively, but they were favored by some water running into the trench. *A. nutans* developed few flower-stalks. Both made an excellent growth in 1922, extending the area of the bunches, but *Andropogon scoparius* alone flowered. In 1923 they again grew rank, reaching heights of 2 feet, and both flowered abundantly. At Burlington there were no survivors of trench sowing.

Denuded Quadrats.

Twenty-eight species were planted in the quadrats at Lincoln (high prairie) on April 14. Eight failed to germinate. *Elymus* and *Stipa viridula* died in June, *Agropyrum* and *Bromus inermis* in July, and *Acer negundo, A saccharinum,* and *Calamovilfa* in August; of these, *Bromus* and *Stipa* were badly damaged by grasshoppers; 13 species survived. *Corylus americana* and *Symphoricarpus* spp., all of which survived, were propagated at the several stations from rhizomes obtained from Weeping Water, Peru, and Lincoln, Nebraska rather than from seed.

Among the 28 species planted in quadrats at Phillipsburg, 9 failed to germinate. Among these were *Koeleria cristata, Liatris scariosa, Muhlenbergia pungens,* and *Onagra biennis,* none of which germinated at Lincoln and all but *Muhlenbergia* failed in the quadrats at Burlington. *Calamovilfa, Sporobolus asper,* and *S. cryptandrus* died in June, *Corylus* and *Pinus* in July, while *Stipa*

viridula succumbed in August. Except for *Calamovilfa,* the losses here and at Lincoln were of different species. Thirteen species survived.

Of 25 species planted on April 30 at Burlington, only 6 did not germinate. Ten species disappeared in June, another in July, and 4 others in August, *Andropogon nutans, Calamovilfa longifolia, Gleditsia triacanthus,* and *Stipa viridula* being the only ones to survive the season. A comparison of the growth of *Gleditsia* and *Andropogon,* the only species that lived at all three stations, is instructive. By the end of the summer the former was 4 to

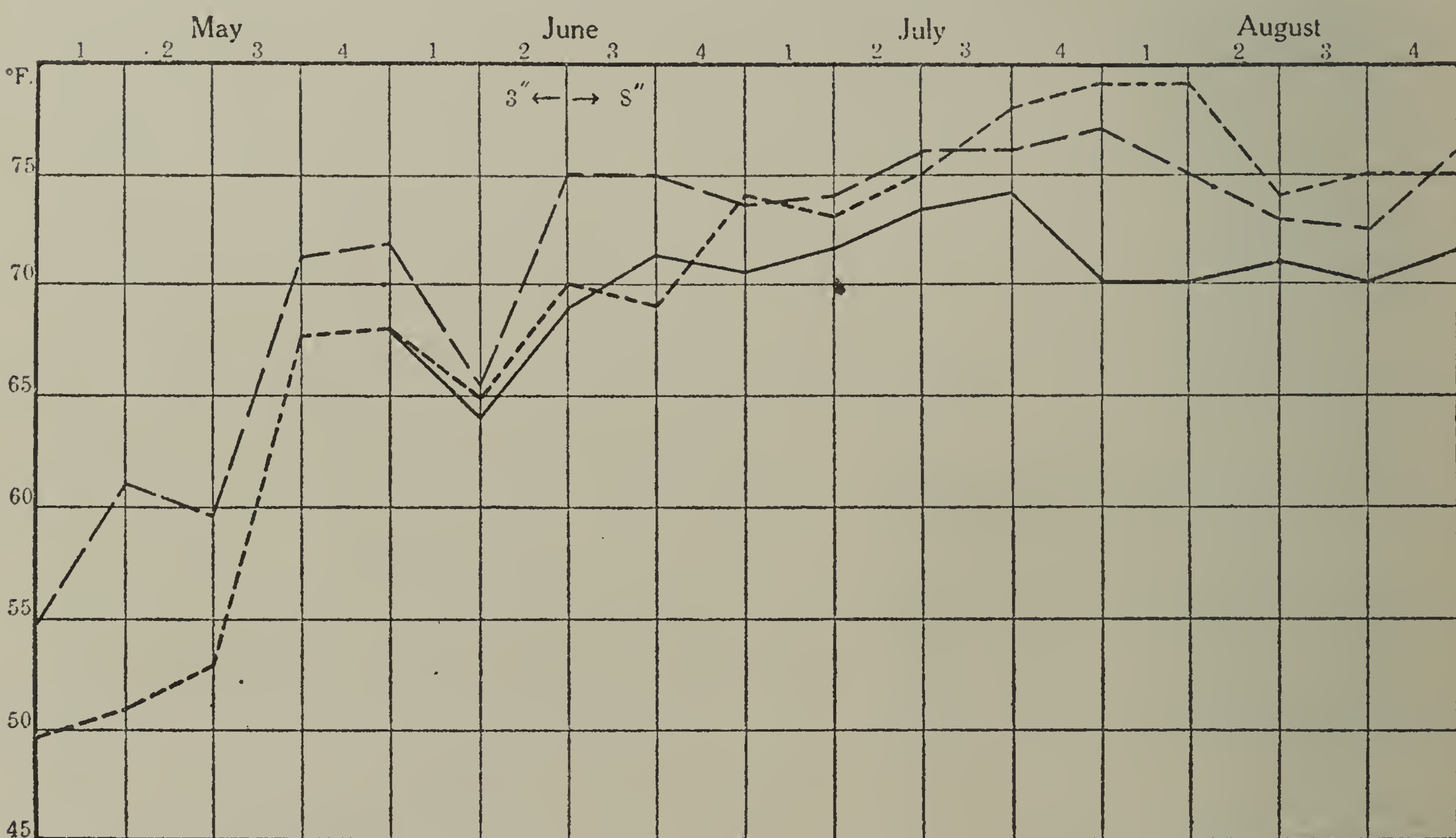

Fig. 26.—Average daily soil-temperature at depths of 3 and 18 inches respectively at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1921.

8 inches tall at Lincoln with 12 to 13 leaves 5 to 10 inches high, with the same number of leaves at Phillipsburg, and only 2 to 3 inches high with 4 to 6 leaves at Burlington. *Andropogon* had formed a dense sod 4 or 5 inches high at Lincoln, one 12 to 18 inches high at Phillipsburg, while at Burlington the scattered growth was only 2 to 7 inches in height.

Of the survivors in the 1920 quadrats at Lincoln, *Stipa setigera* and *S. eminens* were winterkilled (table 58). *Andropogon nutans* and *A. scoparius* flourished, forming good sods 10 to 13 inches tall, the former having flower-stalks at 2 feet. *Stipa viridula* and *Aristida purpurea* developed good bunches 6 or 7 inches in height. *Bouteloua gracilis* and *Elymus* blossomed, the *Bouteloua* tufts being 4 to 6 inches tall and those of *Elymus* 12 to 15 inches. All made a good growth during 1922, but *Andropogon scoparius* and *Bouteloua gracilis* alone came into blossom, probably owing to the severe drought in late summer. None died during the very dry winter following (table 58).

At Burlington, only 3 species, *Andropogon nutans, Liatris punctata,* and *Stipa viridula,* survived the 1920 season in the denuded quadrats. The vicissitudes of these plants are of interest (table 60); wilting and rolling of the leaves, dying back, and discoloration were of usual occurrence. However, they were well rooted and all survived the summer of 1921, notwithstanding

the ravages of grasshoppers and drought. In 1922, all but *Stipa viridula* blossomed. The flower-stalks of *Andropogon nutans* were 1 to 2.5 feet high late in August, while *Liatris* flowered profusely. *Stipa* exhibited many fine clumps 12 to 18 inches tall in 1923. As in the other quadrats, its area had been scarcely invaded, but it did not blossom. All the species prospered and

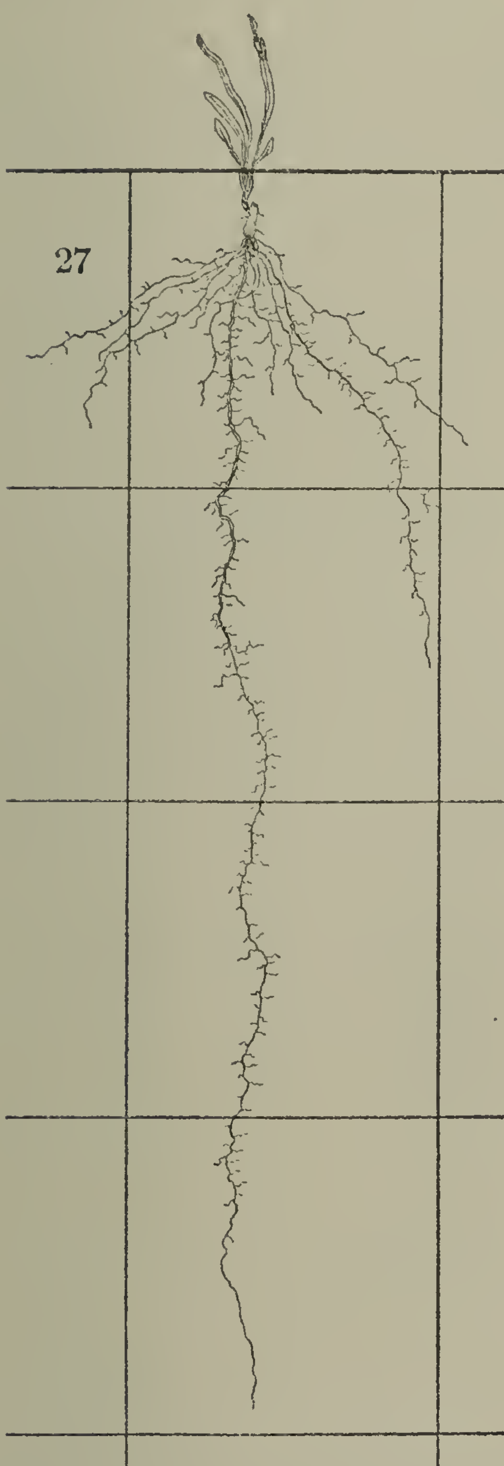

Fig. 27.—*Liatris punctata* from Phillipsburg, on July 1 of second year after planting.

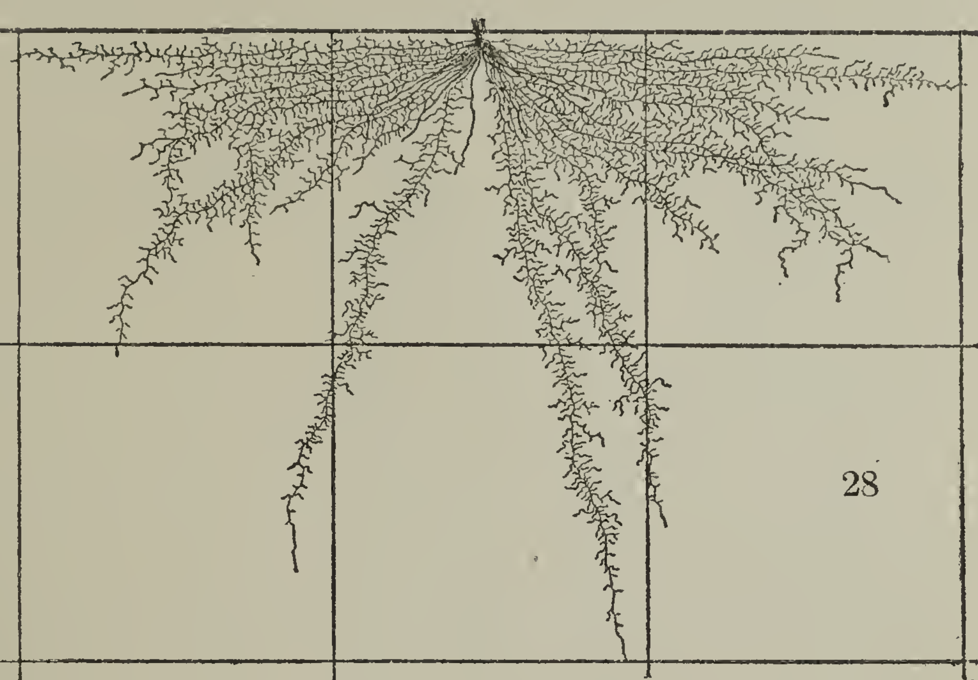

Fig. 28.—*Bouteloua hirsuta* from Phillipsburg, on July 1 of second year after planting.

seemed permanently established, at least as long as competition with the short-grasses did not occur (table 60).

Root Development in Denuded Quadrats.

From July 1 to 3 several species from the 1920 quadrats at Phillipsburg were excavated and the root development studied. *Liatris punctata* had 5 leaves and a height of 5.5 inches. The portion of the root which began 2 or 3 inches below the surface was 5 mm. in diameter for a distance of about an inch, beyond which it tapered rapidly and descended more or less vertically downward to a depth of nearly 4 feet (fig. 27). Nine branches came off from the tap in the first 8 inches of soil, none of which exceeded 17 inches in length. Like the tap-root, they were fairly well supplied with short branches.

Bouteloua hirsuta formed fine, well-tillered clumps 6 to 9 inches tall. The root system was characterized by its wide-spreading habit in the surface soil. The delicate, thread-like, exceedingly well-branched roots reached a distance of 16 to 18 inches on all sides of the plant, the longest ones often lying in the surface inch or two of mellow soil (fig. 28). The deeper roots, which ran

obliquely downward, extended to depths of 12 and a few to 24 inches. Many new thick, white roots only 2 to 4 inches long came off from the new tillers. *Bouteloua gracilis* had well-developed clumps 4 to 7 inches high. The fine fibrous root system was very similar to that of the preceding, especially in the number and extent of fine lateral branches. However, it differed in having a smaller lateral spread (about 12 inches) and greater depth of penetration. Many of the roots reached 2 and some nearly 3 feet in depth.

Andropogon scoparius produced densely rooted plants 8 to 12 inches tall and so well tillered that they formed a continuous sod. The dense network of roots and branches reached a working level of 30 inches and a maximum

29 30 31

Fig. 29.—*Andropogon scoparius* from Phillipsburg, on July 1 of second year after planting.
Fig. 30.—Roots of *Andropogon nutans* after the block of sod had been transplanted for 2.5 months at Burlington.
Fig. 31.—Roots of *Elymus canadensis* at end of June of second year after the block of sod had been transplanted and watered at Burlington.

depth of 37 inches. Many new roots of the current season's growth were only 6 to 12 inches long. The last 3 to 8 inches of these, as well as those of many of the rapidly growing ones of 1920, were 1 to 1.5 mm. thick, glistening white, and destitute of branches (fig. 29). *Stipa viridula* was represented by bunches 4 to 9 inches in height. The roots were abundant to a depth of 2 feet, some extending to the 4-foot level. They had a lateral spread of 12 to 14 inches on all sides of the plant. These data are sufficient to show the fairly deep root penetration of the species by midsummer of the second year in denuded quadrats. It also explains how they persist so tenaciously during periods of drought after they have had a year's growth.

The removal of the preceding species left *Andropogon nutans* alone in the 1920 quadrats. It grew very well, reaching a height of 15 to 18 inches by fall and producing a few flower-stalks 40 inches tall. During 1922 it made ex-

cellent growth but did not blossom, while in 1923 it reached a height of 2 feet and flowered abundantly.

Seedling Transplants.

Seedlings of 13 species were transplanted into high prairie on May 11, when 3 or 4 weeks old (table 61). As at all stations, these seedlings were thoroughly watered when planted and during a period of 10 days thereafter whenever necessary. Notwithstanding this care, two weeks later two of the four lots of *Andropogon nutans, Aristida purpurea, Bouteloua racemosa,* and *Koeleria cristata* had died. *Agropyrum glaucum, Elymus canadensis, Stipa comata,* and *S. viridula* were eaten back by grasshoppers and many individuals had died. One lot of *Bouteloua gracilis* had also died, and *Andropogon furcatus, Stipa spartea,* and *Liatris punctata* were the only ones which had not suffered a high mortality. The soil at this station is of such a type that it becomes quite compact following heavy rains or watering. This is detrimental to seedlings, as well as germinating seeds, since the surface crust hinders aeration and offers more or less of a mechanical barrier to tender growing parts. When dry it cracks and in this way injures the plants by mechanical tearing of roots, rhizomes, etc., near the surface. At Phillipsburg and Burlington the soil is of such texture that it is mellow at all times. However, all species were represented until the middle of June, after which *Stipa comata* and *S. viridula* died, and *Agropyrum, Aristida, Elymus,* and *Liatris* also succumbed during July. The other 7 species came through the season in fair to excellent condition, although much reduced in number. *Bouteloua hirsuta* flowered.

A similar lot of seedlings of the same age was transplanted at Phillipsburg on May 19. These were in groups varying from 2 to 6 per species (table 62). By June 9 all were flourishing and most of them continued to do so throughout the month. By July 25, *Agropyrum, Elymus,* and *Stipa spartea* had suffered heavy losses; *Koeleria, Stipa comata,* and *S. viridula* were nearly all dead, and by the end of the summer they had disappeared. *Agropyrum, Andropogon furcatus, Bouteloua gracilis, Elymus,* and *Liatris scariosa* were nearly all dead or dying, the last having been eaten to the ground. However, *A. nutans, B. hirsuta, Liatris punctata,* and *Stipa spartea* were in fair to excellent condition.

Seedlings were transplanted at Burlington on May 20 (table 63). By June 10, *Koeleria* had died, while *Agropyrum, Liatris scariosa,* and *Stipa viridula* had suffered a high mortality. However, the other species were in fairly good condition. By the end of the month, *Liatris scariosa* and *Stipa viridula* had succumbed and most of the other species had lost heavily. Many had their leaves rolled or were badly wilted. By the end of July, *A. nutans, B. hirsuta,* and *B. gracilis* alone were barely alive and these died during August.

Summary.

The sequence of germination was the same as in preceding years (table 24), i. e., Lincoln being highest (81 per cent), Phillipsburg second (68 per cent), and Burlington last (43 per cent). On the basis of establishment, however, Phillipsburg, unlike the preceding year, ranked first with 60 per cent, Lincoln second (40 per cent), and Burlington third (7 per cent) The

unusually favorable rainfall at Phillipsburg during spring and early summer has already been pointed out, as well as the relatively favorable light conditions for surface-sown plants (p. 60) .

On the basis of survival of seedlings, Phillipsburg also ranked first, none surviving at Burlington. As to the surface-sown plants of 1920, none were left at either Lincoln or Phillipsburg for growth during 1921, but *Stipa viridula* survived at Burlington. Among the 5 survivors of the 1920 trench planting at Lincoln, none died during 1921; 1 was winterkilled in 1921–22, but the others were growing fairly well at the end of the summer of 1923. At Phillipsburg only 2 of the 6 species planted lived, but both of these grew well, flowered from time to time, and persisted to the end of 1923. None survived the 1920 summer at Burlington. Among the 8 survivors in the 1920 quadrats at Lincoln, all lived throughout the next summer, but 2 were winterkilled. The 6 remaining species did well until the fall of 1923. At Phillipsburg all but 1 were excavated for root study. This plant made an excellent growth and flowered from time to time until the end of 1923. The 3 species at Burlington lived not only through the 1921 season, but also during 1922 and 1923, all but *Stipa viridula* coming into blossom.

TABLE 24.—*Summary of planting experiments at the three stations, 1921.*

Method of planting.	P. ct. of species germinating.			P. ct. of germination established.		
	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.
Surface sowing	79	100	38	9	83	0
Trench	92	43	15	45	50	0
Denuded quadrat	71	61	76	65	63	21
Average	81	68	43	40	65	7
Seedlings				54	75	0

SOD TRANSPLANTS.

Between March 20 and 31, sods of 16 species were planted on high prairie (table 64). *Distichlis* was secured from the salt-flats, *Bulbilis* from overgrazed low prairie, *Bouteloua gracilis* and *B. hirsuta* from gravel-knoll, *Andropogon furcatus, A. nutans, Panicum virgatum,* and *Poa pratensis* from low prairie, and *Spartina cynosuroides* from the swamp. The rest were high-prairie species. All made a good growth during the summer, except *Distichlis*, which was nearly all dead by August 31, and all blossomed except the three *Andropogons, Bouteloua hirsuta, B. gracilis, Koeleria,* and *Spartina.* During 1922 all not only survived, but *Bulbilis, Panicum,* and *Spartina* increased their area. However, by the end of August, *Agropyrum, Distichlis,* and *Elymus* were doing very poorly, owing in part to the severe drought. Twelve of the 16 species blossomed (table 64). *Koeleria* died during the following winter. The rest survived the following summer, but by August *Bouteloua gracilis, Agropyrum, Distichlis,* and both lots of *Elymus* were in straits. *Bulbilis, Stipa,* and *Panicum* alone produced flower-stalks before the final check was

made in August. This lack of vigor was probably a result of the extremely dry late summer, fall, and winter preceding (p. 109). The 1920 sods made fair to good growth, except for one block of *Andropogon furcatus* and two of *Distichlis*, which were nearly dead by the last of August. The following did not blossom: *Agropyrum, A. furcatus, Bouteloua gracilis, B. racemosa, Distichlis, Spartina,* and *Stipa.* During 1922 a severe drought occurred in late summer and both plantings of *Distichlis* and *Elymus* and one of *Koeleria* succumbed. *Agropryum,* one *Andropogon scoparius,* and *Poa pratensis* were in very poor condition at the end of the summer, while *Andropogon nutans, A. scoparius, Poa,* and *Stipa* alone had seeded. The following winter one *Stipa* died, but all of the others made a fair to good growth during this fourth summer. On August 25 only the following had blossomed or showed signs of developing flower-stalks: *Poa, Bouteloua gracilis, B. racemosa, Koeleria,* and *Panicum.*

Sods of the same species as those used at Lincoln during 1921, except *Bouteloua gracilis, Bulbilis, Distichlis,* and *Spartina,* were secured from the various stations at Lincoln and transplanted into the short-grass sod at Burlington on April 15. As in 1920, they were placed in duplicate rows, one being thoroughly watered 5 times during the season (table 65). By May 20 the effects of drought were apparent. The leaves on many species were rolled and the leaf-tips dead. Others had been frayed by whipping in the wind, a very common phenomenon in this region among both native and crop plants. *Koeleria* and *Stipa* were almost dead. The plants in the watered row were in better condition.

On June 29, the root development was examined in two species, which had been growing for a period of 75 days. *Andropogon nutans* was in fairly good shape and had made a growth of 4 to 6 inches. The block of sod was found to be in close contact with the soil on all sides. The old roots had practically all died, though in a few instances laterals from them had continued growth. Many new white roots had originated from the rhizomes and ended at 6 to 12 inches depth. They were evidently growing rapidly, since 3 to 6 inches of the tips were unbranched; nearer their origin they were thickly beset with short branches. Several longer roots penetrated from 18 to 32 inches, but none spread much laterally, and all were well branched (fig. 30). The soil was moister under the block of sod than elsewhere to a depth of 20 inches. *Panicum virgatum* was growing nicely and had reached a height of 10 inches. As before, the old roots were nearly all dead, but many new ones descended vertically and were fairly abundant to 24 to 30 inches. At the last depth they came in contact with the dry hard-pan. They were densely beset with laterals to near the tip.

By June 29, *Stipa* had died in the unwatered row and *Elymus* and *Koeleria* were nearly dead. Even some of the species in the watered row were doing poorly, especially *Poa* and the three andropogons. By late July *Andropogon nutans* and *Poa* had died in the watered row and several other species were in bad condition. In the unwatered row, *Elymus* and *Poa* had succumbed, while *Andropogon furcatus, Bouteloua hirsuta,* and *Koeleria* died soon after. Autumn found only 7 of the 11 species alive in the watered row, and these were represented by mere remnants of the original fine blocks of sod. Of the survivors, *Agropyrum, A. scoparius, Bouteloua hirsuta, Elymus,* and *Stipa* were high-

prairie species, and *A. furcatus* was from the lowland. *Agropyrum* alone had blossomed. Of the 11 duplicate unwatered species (2 having been dug up) only *Agropyrum, Bouteloua racemosa,* and *Andropogon scoparius* remained, and *Agropyrum* alone had a single flower-stalk.

During 1922, both *Agropyrum* and *Bouteloua racemosa* in the unwatered row survived, although both suffered severely from drought, and *Andropogon scoparius* was winterkilled. *Agropyrum* put forth flower-stalks mostly less than a foot high, and the spikes were very much dwarfed. In the lot that were formerly watered, *Andropogon scoparius* died in July. The other 6 species made a fair to good growth, often showing the effects of drought in the rolled leaves or dead leaf-tips, as well as by the dwarfing of the whole plant. *Bouteloua racemosa, B. hirsuta, Agropyrum,* and *Elymus* alone blossomed. *Andropogon furcatus, Bouteloua hirsuta,* and *Bouteloua racemosa* died before the next spring. The single survivor of the unwatered lot, *Agropyrum,* reached a height of only 11 inches the following summer, and did not blossom or extend its territory into the surrounding short-grasses. *Agropyrum* in the other lot grew only slightly better, *Elymus* was represented by only 2 shoots, and *Stipa* by a small c'ump, while *Bouteloua racemosa* alone made a good growth and seeded. Although the season was unusually favorable for growth, the results indicate that one more year would probably have been sufficient to eliminate most if not all of the transplants. As to the growth of the 1920 transplants at this station, it may be recalled that none died during the first season, even in the unwatered row, but all suffered from drought and were dwarfed. During 1921 none were watered.

Root Development.

On June 28–29 the root development of several species was examined. *Elymus,* which had blossomed the preceding season, had made a fair growth in the unwatered row, reaching a height of 21 inches with flower-stalks appearing. The old roots had not renewed their growth, but laterals on them were functioning (fig. 31), and in one case a large lateral had replaced the cut main root. It was traced to a depth of 20 inches. Many new roots reached a depth of 18 inches, while a few penetrated to the hard-pan, about 30 inches deep. All were quite profusely branched to near the tips, and the lateral spread was about 12 inches. Some new roots, evidently of the current year's growth, extended just through the old block of sod.

Andropogon furcatus was excavated in the unwatered row. The original sod, which was in complete contact with the soil, was a foot square and 8 inches deep. The new growth of leaves was about 8 inches high. Most of the old roots had died, but new ones had grown out thickly from the rhizomes. Many of these penetrated to the hard-pan layer at 28 to 30 inches, but only slightly into it. All of the roots were well branched, but were very dry, like the soil in which they grew. The dry, mellow loess below the hard-pan layer (which was 8 to 12 inches thick) contained roots of the short-grasses and *Psoralea.* There was very little lateral spread of the roots beyond the area occupied by the original block of sod.

Koeleria, Stipa spartea, and *Panicum virgatum* were excavated in the watered row, which had also received some run-off water because of its location near a furrow separating an adjoining plowed area. The clump of

Koeleria was 3.5 inches in diameter and had flower-stalks 12 inches tall, with rather normal spike development at a height of 6 to 15 inches. The roots, although very fine, were easily distinguished from those of the short-grasses by their yellowish color and slightly larger size. A great mass of profusely branched roots filled the soil to a depth of about 18 inches, a few penetrating 8 inches deeper. A lateral spread of 14 inches in the surface inch of soil was determined, the occupation of a considerable area on all sides of the plant being characteristic of the species.

Stipa spartea had made a growth of 2 feet, with 5 flower-stalks, some of which were 34 inches tall, and formed a representative clump. The roots reached a maximum depth of 34 inches in the fairly moist soil, many ending at or above 2 feet. The lateral spread was about normal (10 inches), but the roots as a whole were more profusely branched than is usual in its native region. *Panicum virgatum*, which flowered the preceding season, had made a good growth, reaching a height of 18 inches. The root development was remarkable. The coarse roots, 2 to 4 mm. in diameter, pursued a nearly vertically downward course to a maximum depth of 7.3 feet, spreading only a little near the surface. The profound branching to the extreme depth of penetration is shown in figure 32. Branches at the rate of 25 per inch were not uncommon, and many of the roots were branched to their tips. In fact, the profuse branching, which undoubtedly was a response to the dry soil, can scarcely be overemphasized. It stood out in marked contrast to the rather poorly developed lateral roots found on plants growing in lowland soil near Lincoln (Weaver, 1919:4).

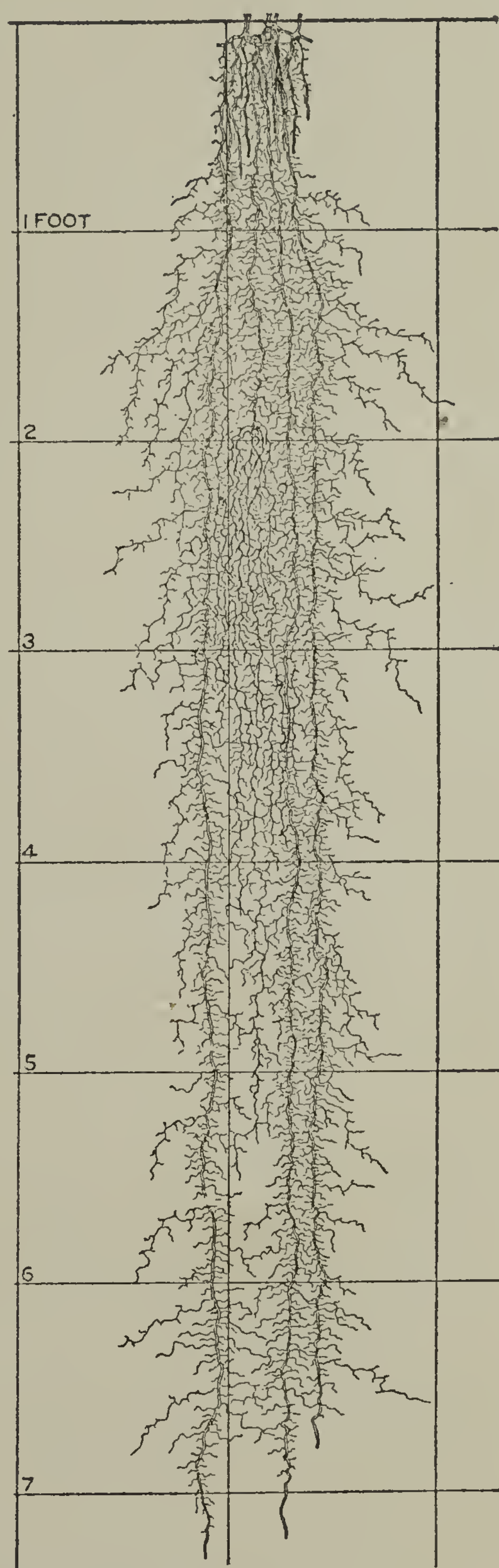

Fig. 32.—Roots of *Panicum virgatum* at end of June of second year after the block of sod had been transplanted and watered at Burlington.

Notwithstanding the root growth of these transplants, the severe drought conditions caused the death of several species. One sod of the watered *Koeleria* and one in the unwatered row succumbed. In the unwatered row, 1 *Andropogon scoparius* was winter-killed, 2 individuals of *Elymus*, and all 3 of *Poa* died. *Agropyrum* was the only species that increased its territory perceptibly. It invaded the short-grass sod on all sides for a distance of about 18 inches, the new shoots from the rhizomes reaching a height of 8 to 13 inches. However, none of these or those of the original block bore flower-stalks. *Bouteloua racemosa*, *Elymus*, *Stipa*, and *Panicum* (in the watered row only) bore a few flower-stalks and seeded, as did also *Poa* and *Koeleria*, the

last in the unwatered row also. All suffered severely from spring and summer drought, and in general growth was poor. Most of the species, including such late bloomers as *A. scoparius*, *A. furcatus*, and *Panicum*, took on their late autumn reddish color, dried out, and went into winter condition by August 1. As a whole, those that had not been watered the preceding season, and hence were less well established, suffered most. During 1922 none of the plants died in the lot which had been watered, but *Koeleria* of the unwatered lot succumbed in July. Of the former, *Agropyrum* had extended its area 3 or more feet on all sides, even into the densest sod. Although it flowered profusely in its original area at a height of about 2 feet, only a few dwarfed flower-stalks appeared in the invaded area. This was the only species which extended its area, though, on the other hand, the short-grasses were unable to invade markedly. Because of the severe drought of July and August, the grasses at this time mostly took on their late autumn or winter color and habit. Aside from *Agropyrum*, *Stipa*, *Elymus*, *Koeleria*, and *Bouteloua racemosa* blossomed; the last, unlike the others, had flower-stalks and inflorescences of about normal size. In the row that was not watered the preceding year, conditions were much more severe. *Agropyrum* possessed only a few flower-stalks, while *Panicum* put forth a few small panicles at 8 inches height. *Elymus* and *Koeleria* also blossomed.

The very dry fall and winter following took severe toll. Of the 15 lots of plants in the area formerly watered, 4 died, while among those less well established 8 succumbed, leaving *Agropyrum* as the sole survivor. Notwithstanding the excellent growing conditions of the following summer (1923), it had no flower-stalks, but had sent out a few rhizomes to distances of 2 to 3 feet. The rest of the plants received extra water from a furrow which was only 2 feet distant and separated the unbroken and broken land. Hence, their growth was very good. *Agropyrum* had spread nearly 4 feet, but no flower-stalks occurred in this sodded area. *Elymus* had also extended its area over a foot, but another block of the same species died. *Panicum*, *Bouteloua racemosa*, and *Stipa* blossomed. Among the forms introduced with the sods, *Erigeron ramosus* blossomed the second year (1921), as did also *Sporobolus asper*, though both died later. *Brauneria pallida* in one instance made a good vegetative development only, while in another case it blossomed normally the second year after transplanting before succumbing. *Aster multiflorus* occurred in several blocks of sod and usually spread a foot or more by rhizomes; it blossomed profusely. In some cases it persisted 4 years near the furrow, but in others it soon succumbed.

EXPERIMENTS AT OTHER STATIONS, 1921.

Physical Factors.

Rainfall and Holard.

Studies on experimental vegetation were continued in the series of edaphic stations at Lincoln, at Nebraska City, and Colorado Springs during 1921. The general conditions of precipitation at Lincoln have already been given (p. 56). The season at Nebraska City was one of drought. The precipitation from February to July was decidedly below normal, that of April, May, and June being 0.86, 1.56, and 0.52 inches respectively below the mean. However,

July had an excess of 5.17 inches, but August was slightly below normal. No efficient rain fell between May 9 and 26 or from June 18 to July 2. The holard at the Nebraska City, low-prairie, and gravel-knoll stations is given in table 25. Notwithstanding the decreased rainfall, the soil at Nebraska City usually had a margin of 10 per cent above the hygroscopic coefficient. In fact, a more constant supply was maintained here than on the low prairie at Lincoln, where the chresard in the surface 6 inches was practically exhausted during the last half of June. An abundant supply was at all times available below the 6-inch level. Even on the gravel-knoll conditions were quite favorable as compared with the preceding year. However, the xerophytism of this habitat is shown by the small chresard, usually only 1 to 6 per cent, even at depths of 3 or 4 feet.

Evaporation and Temperature.

The average daily evaporation at Nebraska City (fig. 33) was considerably lower (often 33 per cent) than on the high prairie. In general, evaporation on the gravel-knoll was greater than on high prairie. This was especially true during the earlier and later parts of the season. The average daily air-temperature at Nebraska City was usually higher than that at Lincoln, and during the first 3 weeks of June it ranged from 2° to 11° F. higher. This was largely due to the much higher average night temperatures (often 6° to 10° F.), since the day temperatures nearly always averaged lower than those at Lincoln. The temperature of the soil at 18 inches was constantly 1° to 3° warmer.

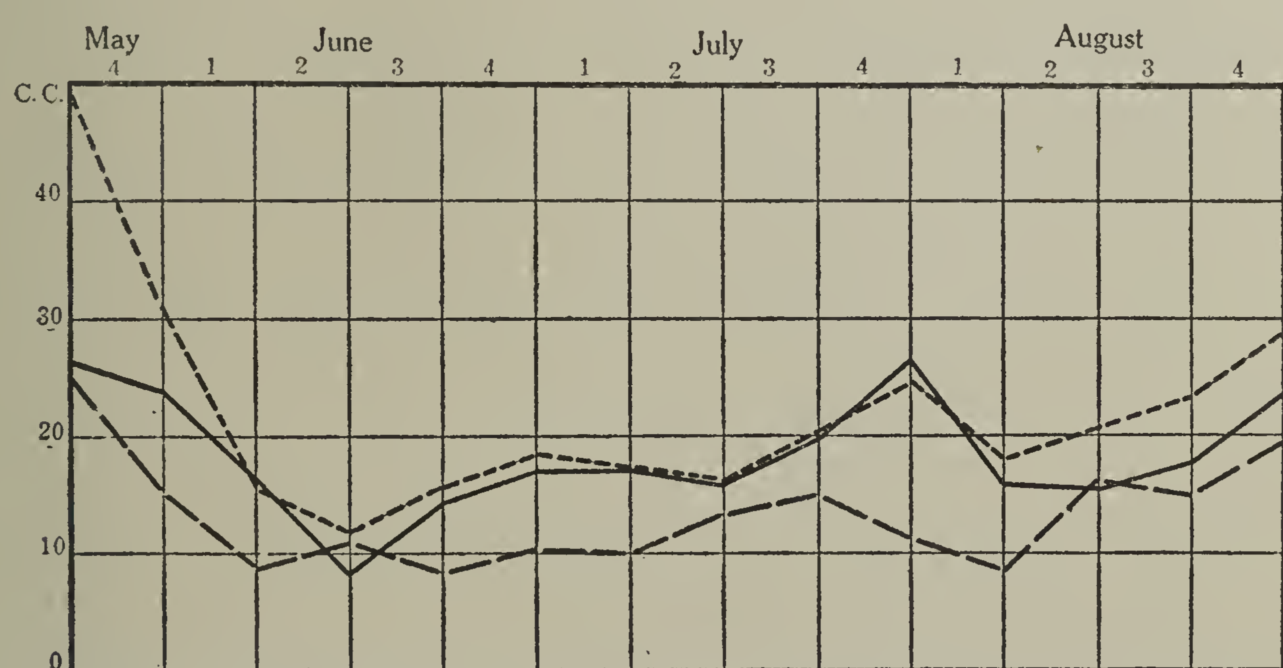

Fig. 33.—Average daily evaporation on high prairie (solid line), gravel-knoll, Lincoln (short broken lines), and at Nebraska City (long broken lines), 1921.

Planting Results.

Surface Sowing.

During 1921, surface sowings were made on the low prairie at Lincoln and at Nebraska City. Of the 9 species planted at Lincoln on April 23, *Aristida purpurea* and *Bouteloua gracilis* did not germinate. *Elymus canadensis* had died by June 27, as the following did also during July and August: *Lespedeza capitata, Liatris punctata, L. scariosa, Sporobolus asper*, and *Stipa viridula*. *Koeleria cristata* was still alive in September, but was missing the following

May. Owing to the low light intensities, all of the seedlings were extremely attenuated as compared with those growing in the quadrats, and were unable to make any real growth. The ability of *Koeleria* to endure shading was noted

Table 25.—*Holard in excess of the hygroscopic coefficient at Nebraska City, Lincoln low prairie, and gravel-knoll, 1921.*

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Nebraska City.					
Apr. 9	24.4	21.4	18.5	11.7	8.7
Apr. 23	19.4	20.1	....	....	....
May 6	10.7	16.5	15.6	....	....
May 20	10.1	16.1	16.8	12.6	12.8
June 3	23.8	21.6	19.5	....	....
June 24	12.0	9.9	15.0	13.6	13.8
July 15	9.2	14.9	14.3	11.5	9.6
Aug. 13	14.8	10.5	16.0	15.9	10.1
Aug. 26	12.8	10.2	10.9	12.5	9.1
Hygro. coeff.	12.1	11.7	12.3	13.7	12.9
Low Prairie.					
Apr. 9	20.8	25.2	....	....	....
Apr. 23	28.4	23.3	21.5	20.5	29.7
May 18	10.5	24.8	21.6	22.3	23.0
May 25	9.7	20.0	....	....	....
June 1	6.8	16.4	....	....	....
June 7	9.7	21.7	21.3	23.9	22.4
June 22	1.4	16.0	19.2	....	....
June 29	0.3	11.1	14.2	16.8	....
July 20	25.4	23.0	15.3	15.2	18.9
July 28	18.2	17.9	....	....	....
Aug. 3	15.0	12.1	14.5	....	....
Aug. 23	12.3	14.9	11.8	13.7	19.3
Hygro. coeff.	11.8	11.1	10.3	10.2	11.9
Gravel-Knoll.					
Apr. 9	6.5	3.9	5.0	5.0	1.0
May 18	6.3	5.3	6.6	9.2	1.7
May 25	0.1	−0.2	....	....	....
June 1	3.3	−0.3	....	....	....
June 7	7.8	6.4	11.8	5.7	1.2
June 22	−0.1	0.4	3.4	4.5	3.9
June 29	1.9	3.3	3.1	3.3	....
July 13	4.5	2.6	3.7	....	....
July 20	4.8	3.1	2.1	4.7	9.6
July 28	0.4	1.3	....	....	....
Aug. 3	4.8	4.0	2.7	....	....
Aug. 10	3.1	2.3	2.0	6.7	10.8
Hygro. coeff.	5.2	4.9	3.1	2.8	7.4

in many instances, this adaptation probably resulting from its smaller stature. Light values at the soil-surface in the several stations are summarized in table 26.

TABLE 26.—*Light values at the several stations.*

Cover.	Per cent.
High prairie, Lincoln.	
May 28, 1922:[1]	
Andropogon scoparius	15
Psoralea tenuiflora floribunda	20 to 26
Psoralea, Kuhnia glutinosa	6
Brauneria pallida	10 to 15
Astragalus crassicarpus	2.5 to 3.5
July 25, 1921:	
Mixed grasses	8.3
Average density	5.0
Light cover	9.5
Medium, 4 inches above surface	15.0
Light	17.0
Trench, medium cover	20 to 23
Swamp, Lincoln.	
May 28, 1922:	
Spartina cynosuroides	7.5
Phalaris arundinacea	6.5
Mixed grasses, etc	4.5 to 20
Mixed grasses, average	11.2
August 24, 1922:	
Spartina cynosuroides	
Densest places	1.5 to 2.6
Medium density	4 to 5.7
Most open	11.4 to 16.6
Nebraska City.	
June 3, 1921:[3]	
Stipa spartea	18
Andropogon furcatus	11.5
Andropogon scoparius	17.5 to 26.5
Liatris scariosa	7.5
Grasses, Amorpha canescens	8 to 11.5
Rosa arkansana	2.5
Brauneria pallida	7
A. scoparius, Koeleria cristata	15
A. scoparius, A. nutans	20
Stipa spartea	8 to 10
Very open grass mixture	60
Ceanothus ovatus	1.5
A. furcatus at side of quadrat	15
June 3, 1922:	
Very open grass mixture	40 to 45
Euphorbia corollata, grasses	20
Rosa arkansana	6.5
Baptisia bracteata	6.5
Vernonia fasciculata	8
A. furcatus, Desmodium	9
Stipa spartea, Andropogon	9
Koeleria cristata, Poa pratensis	22 to 26
Ceanothus ovatus	2 to 2.5
Low prairie, Lincoln.	
May 28, 1922:	
Mixed grasses:	
Above 1921 growth	7.5 to 28
Average	16
Under old growth	3.4 to 14
June 14, 1922:[2]	
Surface seeding, average density	5 to 7
Side of 1922 trench:	
Spartina cynosuroides	12.5
Verbena stricta	5
Light, mixed	12
Andropogon furcatus	7 to 12
Grasses, Art. ludoviciana	8 to 13
Lighter mixed cover	26
South edge of 1922 quadrats	15 to 27
West edge of 1922 quadrats	10
July 25, 1922:	
Mixed grasses:	
Average density	2.5 to 4
Lighter	12
Very dense	1.5
4 inches above trench surface:	
Medium	11
Lighter	16
Dense	4.5
Phillipsburg.	
June 10, 1922:	
Bouteloua gracilis and Bulbilis dactyloides	60 to 80
Psoralea tenuiflora	35
Elymus canadensis	24
Andropogon furcatus	3 to 8
A. scoparius	4 to 5
Bouteloua, Gaura, Lygodesmia	10
Verbena stricta	11.5
Grasses:	
Edge of 1922 trench	30 to 33
Edge of 1921 quadrat	20 to 26
Burlington.	
June 11, 1922:	
Bulbilis dactyloides[4]	45 to 50
Bulbilis, B. gracilis, open[4]	71 to 83
Bulbilis, very dense[4]	25
Agropyrum glaucum[5]	20 to 43
Stipa spartea	15
Short-grasses:	
Malvastrum coccineum[4]	43
Erysimum asperum[4]	26
Edge of 1922 trench	56
Edge of 1920 quadrat	20
Edge of 1922 quadrat	37.5 to 45

[1] Burned over in late winter.
[2] This portion of the area burned over in late winter.
[3] Mowed the preceding September.
[4] Photometer sunken so as to be level with soil surface.
[5] Transplanted sods.

Of the 9 species sown on the surface at Nebraska City, *Liatris scariosa* and *Pinus ponderosa* failed to germinate, squirrels having eaten the seeds of the latter. A single plant of *Elymus* was found, but it died before June. By June 24, *Liatris punctata* and *Bromus inermis* were also dead, the latter having been eaten to the ground by grasshoppers. *Sporobolus asper* and *Stipa viridula* (also somewhat eaten) died in later summer. *Bouteloua gracilis* and *B. hirsuta* survived the season, reaching a height of 1 or 2 inches, tillering somewhat, but persisting as very delicate seedlings.

Of the 1920 surface sowing (p. 43), *Koeleria* alone survived the first summer on the low prairie, but was then winterkilled. At Nebraska City, 4 species, *Andropogon scoparius, A. nutans, Bouteloua hirsuta,* and *Elymus canadensis* survived. During 1921 a single small weak survivor of *B. hirsuta* remained alive until July 15, when it succumbed. The other species had become indistinguishable from the general plant cover by midsummer.

Trench Sowing.

Plants in the trench at Nebraska City did even more poorly than those on the surface. *Aristida purpurea, Bouteloua gracilis, B. hirsuta, Liatris scariosa, Pinus ponderosa,* and *Stipa spartea* did not germinate, squirrels having eaten the seeds of *Pinus.* By June 24, *Elymus canadensis, Liatris punctata,* and *Sporobolus asper,* all represented by a few plants only, had died. *Calamovilfa longifolia,* which had germinated abundantly, also succumbed in July. *Bouteloua racemosa* survived the first season, tillered rather freely, and reached a height of 4 to 7 inches; however, it was winterkilled. *Andropogon nutans* alone survived, and it was represented by a good stand that had reached a height of 10 to 15 inches by fall.

Out of 11 species planted in a trench on the gravel-knoll April 20, *Aristida, B. gracilis, Koeleria, Lespedeza,* and *Liatris scariosa* failed to germinate. A few of each of the following species germinated, the two last dying almost at once and the rest during June: *Elymus, Liatris punctata, Sporobolus, Stipa viridula. Pinus* died in July and *Andropogon nutans* alone survived, being represented by a few plants 4 to 5 inches tall in September. These lived over the winter, but were doing poorly in May 1922, and all died in June. Six of the 8 species planted in the low-prairie trench germinated, but *Bouteloua gracilis, Lespedeza capitata,* and *Liatris punctata* died soon after. *Elymus canadensis* succumbed to dense shading in June, and *Stipa viridula,* which was represented by only 3 delicate plants, in July. *Aristida purpurea,* similarly undeveloped and few in number, consisted of a few remnants 4 to 6 inches tall in late summer, but unfortunately these were dug up in transplanting sods.

Of the seedings in the trench on the gravel-knoll during 1920, *Andropogon scoparius* and *A. nutans* were the only survivors, and these were in a very poor condition. Both made a feeble growth and died late in June 1921. In the low-prairie trench, 4 species survived the first season (1920), but all showed the effects of shading. Of these, *Stipa viridula* and *Bouteloua hirsuta* made a poor growth the next spring and died in July. *Andropogon nutans* and *Elymus canadensis,* although much attenuated, made a good growth, reaching heights of 12 to 15 inches. In 1922 a small clump of each reached a height of about 32 inches, but neither blossomed, owing to the

dense shade. However, the following summer both blossomed at a height of 2.5 feet. At Nebraska City all but 4 of the 1920 species planted in the trench survived, but *Bouteloua gracilis* died the following winter. *Liatris punctata* and *Elymus* were both quite abundant in May 1921, but succumbed during June and July. *Andropogon nutans* and *A. scoparius* came through the second season in a thriving condition, reaching a height of 5 to 9 inches. A sparse growth of *Bouteloua hirsuta* also survived the season, but the plants were quite delicate. During 1922, *Bouteloua* succumbed during August drought, after making a good growth earlier. The two *Andropogons* formed good sods 10 to 13 inches tall; both grew well in 1923, but neither blossomed.

Growth in Cultivated Soil.

Native species made remarkable development when grown in narrow rows (trench method) in fertile cultivated soil, kept at a favorable holard at all times, and free from competing species (table 27). These were planted on April 22 and 23 on a level area of soil, the physical and chemical composition of which was almost identical with that of the cultivated lowland area already described (p. 41). Potatoes had been grown on the area the preceding year. A month before planting a good seed-bed was formed by plowing and repeated

Table 27.—*Growth of species in cultivated soil, 1921.*

Species.	Aug. 2.	Oct. 11.
Agropyrum glaucum	Excellent growth, 14 in. tall.	Excellent growth, 18 in., no flower-stalks.
Andropogon nutans	Excellent, 24 to 32 in.	Lvs. 2 ft., flower-stalks 3 to 5 ft., seed ripe.
Aristida purpurea	Fine, 12 in. tall.	Fine bunches 1 ft., flower-stalks 18 to 20 in., abundant, seed ripe.
Bouteloua gracilis	Excellent, 1 ft., flower-stalks to 2 ft., abundant blooming.	Lvs. 16 to 18 in., flower-stalks 23 to 33 in., seed ripe.
Bromus inermis	Good 10 to 15 in.	Lvs. 9 in., dense growth, flower-stalks 18 in.
Calamovilfa longifolia	Excellent 20 to 24 in.	Fine development, 24 to 27 in.; flower-stalks 3 to 5 ft.; seed ripe.
Elymus canadensis	Fine, flower-stalks 2 to 2.5 ft., heads 5 to 5.5 in. long.	Fine 15 to 18 in., heads abundant at 30 in.
Gleditsia triacanthus	Good, 7 to 14 in.	Good, 13 to 20 in., stems 7 to 10 mm. diameter.
Lespedeza capitata	Good, 4 to 5 in.	Good, 5 to 6 in.
Liatris punctata	Good, none over 5 in.	Good, 4 to 6 in., max. of 7 lvs.
Muhlenbergia pungens	Excellent, 6 in.	Flower-stalks 15 to 18 in. seeded; bunches 12 to 16 in. diameter, 8-in. lvs.
Onagra biennis	Rosettes abundant, 2 to 3 in. tall, 6 to 7 lvs.	Rosettes 5 to 8 in. diameter, 2 to 3 in. tall.
Robinia pseudacacia	2 to 3.5 ft., excellent.	5 to 5.5 ft. stems over 0.5 in. diameter.
Sporobolus asper	Excellent, 20 in.	Bunches 3 to 3.5 in., flower-stalks abundant, 3 to 4 ft., seed ripe.
Stipa spartea	Good growth	Lvs. 15 to 22 in., very broad; no flower-stalks.
Stipa viridula	20 to 22 in., fine.	Excellent; no flower-stalks.

harrowing (Weaver, Jean, and Crist, 1920, p. 80). The growth made during the first season by *Andropogon nutans* and *Calamovilfa longifolia* is shown in plate 10B and 11A, and that of *Bouteloua gracilis* in plate 11B.

ROOT DEVELOPMENT AT LINCOLN.

Pinus ponderosa reached a height of 1.5 inches when 45 days old (June 6). The first whorl of leaves was as long as the cotyledons, while the strong, vertically descending tap-root had penetrated to a depth of 13 inches. The root was 1 mm. in diameter, brown in color, and had no laterals over 4 cm. long. These were usually about 2 cm. in length, white near the end, and entirely unbranched (fig. 34). *Liatris punctata* of similar age had a single leaf, 2 to 4 inches high, in addition to the cotyledons. The glistening white tap-roots, which had already stored some food in their enlarged upper parts, tapered rapidly and reached depths of 10 to 16 inches. They descended almost vertically and gave off but few short, unbranched laterals (fig. 35).

34

35

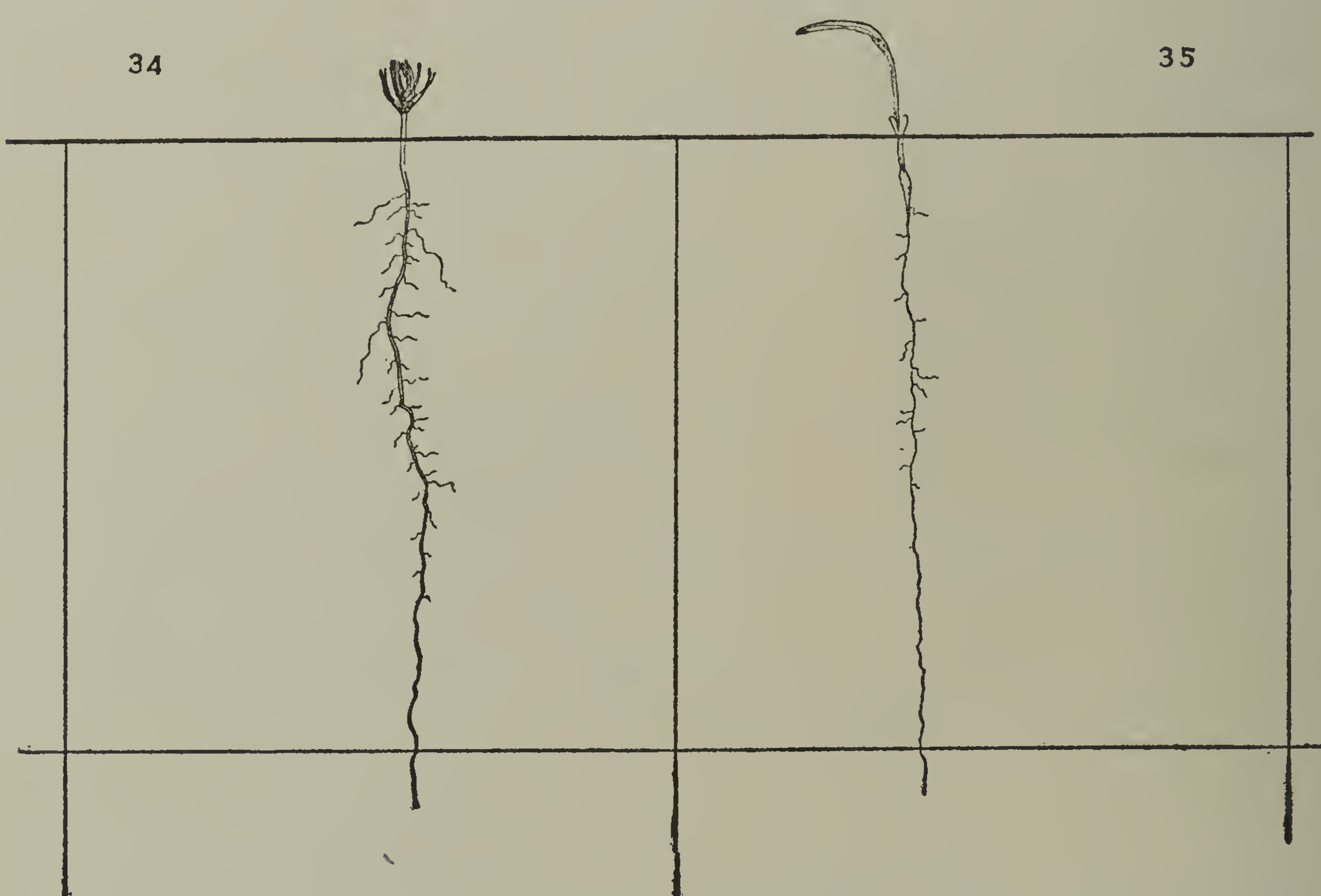

FIG. 34.—*Pinus ponderosa* 2.5 months old. FIG. 35.—*Liatris punctata* 2.5 months old.

Robinia pseudacacia seedlings 45 days old had about 6 compound leaves and a height of 5 inches. The tap-roots, which were about 1 mm. in diameter, tapered rapidly, but regained their maximum diameter again in the vigorously growing unbranched portion of the tip. The much branched tap-root descended irregularly to a depth of 12 to 15 inches; branching began about an inch below the surface and continued at the rate of 10 to 20 per inch, some of the horizontal laterals having a spread of 5 inches (fig. 36).

The root development of *Gleditsia triacanthus* was even more remarkable. On July 12, when 81 days old, the trees had a height of 7 to 9 inches and 15 to 17 compound leaves. The tap-roots reached depths of 30 to 40 inches. The course was rather directly downward, long branches being given off profusely to a depth of 20 inches. Below this for 9 to 12 inches many shorter

ones arose, while for the rest the tap-root was unbranched. The great spread of the longer horizontal laterals (12 to 18 inches), their large number and their characteristic branches, which as often pursued an upward as a downward course, are shown for one of the largest and best developed root systems in figure 37.

The rosettes of *Onagra biennis* were 5 to 8 inches in diameter and 2 to 3 inches tall on October 5. The glistening white tap-roots, 5 or 6 mm. in diameter, penetrated downward in a somewhat devious course, tapering to 1 mm. in width at 1.5 feet, but reaching a depth of 39 to 44 inches in the stiff wet clay. Branches to the number of 100 were produced just below the soil surface and extended to a depth of 1 foot. These varied from 1 cm. to 6 inches in length in a few; they ran off rather horizontally and were poorly rebranched. Below a foot the branching was much less pronounced (3 to 6 per inch of tap-root) and the laterals short. In the deeper soil the tap-root took on the appearance of a delicate white thread.

FIG. 36.—*Robinia pseudacacia* 2.5 months old.

Near the end of the growing-season (October 5 and 6), the root development was examined in *Muhlenbergia pungens* and *Calamovilfa longifolia*, both characteristic sandhill species but growing here in rich silt-loam. The former was represented by bunches 12 to 16 inches in diameter and about 8 inches in average height. Flower-stalks 15 to 18 inches tall were abundant (plate 12A). The root development was marked, roots being traced in the clay subsoil to a maximum depth of 2.5 feet; they were very abundant in the first 22 inches. Many new roots, with thick, white, rapidly growing tips ended in the first foot, some of these originating from the prostrate stems. All branched profusely upon entering the soil. However, there were not so many surface roots as described for sandhill specimens (Weaver, 1920:89), but this may have been due to the age of the plants. Fine laterals were exceedingly numerous, as many as 30 to 50 per linear inch. While most of these were only 1 cm. or less in length, others were 8 to 9 cm. long All were profusely and minutely branched, the larger ones to the third and fourth order, many even to the tips, although some that were growing rapidly were wide and free from branches.

Calamovilfa longifolia had made an excellent growth, having leaves 24 to 27 inches high and an abundance of flower-stalks at 24 to 27 inches. Many tough, wiry rhizomes, thickly covered with long scales and tipped with buds an inch long with very sharp, hard points, extended out on all sides of the

clumps for distances of 6 to 8 inches. Multitudes of tough, wiry roots penetrated the soil vertically or obliquely downward to depths of 5 feet and some extended beyond a depth of 6 feet. Beginning just below the soil-surface and extending to near the tips of the larger roots, laterals well provided with

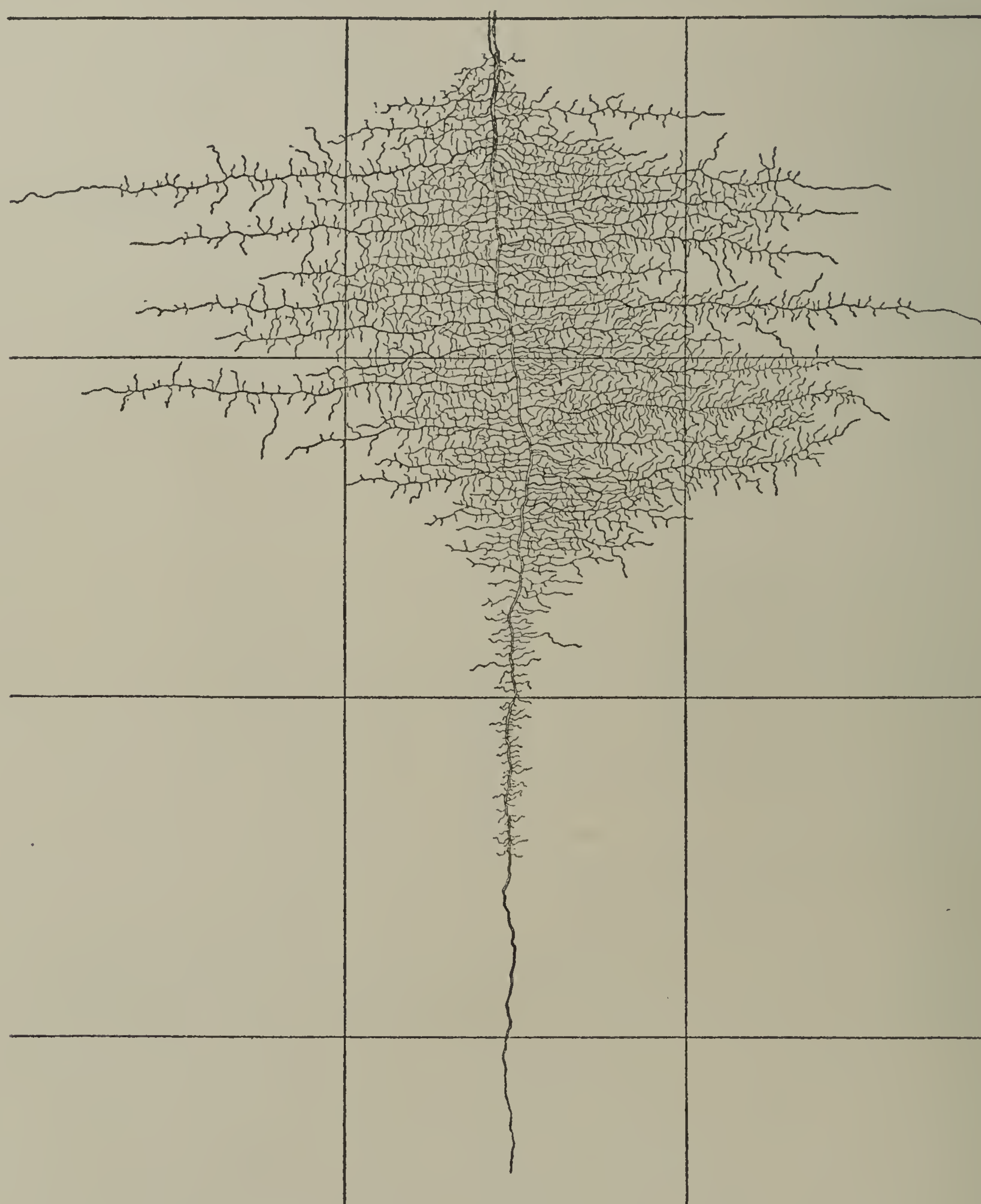

FIG. 37.—Root system of *Gleditsia triacanthus* less than 3 months old.

branches to the third and fourth order were abundant. Most of the major laterals were only an inch or two long, but with the main roots they thoroughly occupied the soil beneath and for several inches on all sides of the clumps (plate 12, A and B).

The excellent growth of all of these native species under favorable conditions, 73 per cent of the grasses bearing seed the first season, emphasizes the keen competition prevailing in stabilized grassland.

SOWING IN DENUDED QUADRATS.

Fourteen species were planted in denuded quadrats on the gravel-knoll, April 14. *Koeleria, Liatris punctata, L. scariosa,* and *Muhlenbergia pun-*

gens did not germinate, while *Lespedeza capitata, Pinus ponderosa, Sporobolus asper,* and *Stipa viridula* germinated in small numbers (except the last, which was abundant), but all died before the end of June. At this time the mortality among the remaining species was also pronounced. *Bouteloua gracilis* and *Calamovilfa longifolia* died in August. *Symphoricarpus vulgaris,* which was propagated from transplanted rhizomes, was nearly dead; *Elymus canadensis* was represented by a single plant 9 inches tall, *Aristida purpurea* by 4 small clumps, and *Andropogon nutans,* which had formed a thin sod, was in poor condition. Thus, while 71 per cent of the species germinated or grew from rhizomes, only 40 per cent of these survived the first summer. Of the 16 species sown in the low prairie, *Koeleria, Liatris punctata, L. scariosa,* and *Symphoricarpus vulgaris* failed to germinate or grow. *Stipa viridula* died during June, but the other species (except *Robinia pseudacacia,* which died in August) lived throughout the summer. Nearly all made a fair growth, but showed the effects of shading, the trees having thin, broad, pale leaves, while those of several of the grasses were much attenutaed.

At Nebraska City, 7 of the 22 species failed to germinate. The seeds of *Pinus ponderosa* had been dug up and eaten by squirrels. *Bouteloua gracilis, Lespedeza, Liatris scariosa,* and *Muhlenbergia* died in June, as did also *Bromus inermis* and *Elymus canadensis,* both of which were eaten to the ground by grasshoppers. All of the others made good growth, shading at this station being less pronounced than on the low prairie. *Andropogon nutans* formed a dense sod (plate 13). *Calamovilfa* was all dead but a few plants, and *Robinia* was represented by a single seedling, grasshoppers having damaged the good stand of early summer.

On the low prairie all the species germinated and all but one came through the season in excellent condition. *Stipa setigera* (seed from California) was winterkilled; the rest made a fine growth until the end of July, *Aristida* and both species of *Bouteloua* blossoming. *Andropogon scoparius, A. nutans, A. furcatus, Koeleria,* and *Elymus* formed good sods and, like *Stipa viridula,* had tillered heavily. *A. scoparius, A. nutans, A. furcatus,* and *Elymus* continued to thrive, reaching heights of 18 to 24 inches, *Koeleria* grew to a height of 7 to 11 inches, and *Bouteloua gracilis* and *B. hirsuta* put forth flower-stalks 18 to 20 inches tall. *Stipa viridula* was so badly shaded that half of the plants died, as did nearly all the tips of the leaves on the remaining plants. Autumn found *Aristida purpurea* also nearly dead or dying. In 1922, one lot of *Aristida* died in May and one of *Stipa* in June, while *Bouteloua hirsuta* succumbed in August. Although the others made a good growth for the most part, *Andropogon nutans, A. scoparius, Aristida, Bouteloua gracilis,* and *Elymus* alone flowered. During the summer of 1923, *Aristida, Bouteloua gracilis, Stipa viridula,* and one lot of *Koeleria* died as a result of the dense shade. While all three andropogons showed a normal development and formed dense sods, *Koeleria* and *Elymus* were clearly losing ground.

At Nebraska City, all of the species in the 1920 quadrats germinated, became established, and lived throughout the summer. However, the mortality among the individuals was high and in general the stand was not as good as on the low prairie. All but *Koeleria* survived the second season. Grasshoppers kept this species eaten back and also made considerable ravages on *Stipa viridula, Liatris punctata,* and *Elymus.* Most of the

grasses tillered heavily, but no sod was formed comparable to that on the low prairie. Neither did they make an equal height-growth, *Andropogon* reaching heights of only 8 to 15 inches and *Bouteloua* 4 to 10 inches. *Andropogon scoparius* and *Bouteloua hirsuta* were the only species that seeded. *Stipa viridula* was winterkilled in 1921–22, but all the rest came through the following summer. *Aristida* and *Elymus* did poorly, but the others made fair to excellent growth, although flower production was not common, probably owing in part to the dry fall. These 3-year-old quadrats were mostly invaded by *Poa pratensis*, species of *Carex*, and *Helianthus rigidus*, but none to the extent of causing serious competition. In 1922–23, *Elymus* was winterkilled, while all the others not only made a very good growth, but some also produced seed.

At Colorado Springs, 7 of the 9 species planted in denuded quadrats in 1920 germinated, and of these 4 survived the first season. During 1921, *Andropogon nutans* and *Elymus canadensis* died, but *Andropogon scoparius* formed an open tufted sod 2 inches high, which covered nearly the whole quadrat and reached a height of 4 inches by 1923. *Stipa viridula* also did well, tillering freely and reaching heights of 6 and 12 inches in 1922 and 1923 respectively.

Root Development at Peru, Nebraska.

A number of species were grown in a well-prepared seed-bed in a cultivated field near Peru, Nebraska, a station about 20 miles south of Nebraska City. The mellow silt-loam soil, underlaid at a depth of 1 to 1.5 feet with a loess of very loose texture, not only absorbs water readily, but has a high water-holding capacity. This ranges from 57 to 64 per cent and is rather uniform to a depth of at least 4 feet, the same type of subsoil extending to depths of many feet. The mechanical analysis of this soil shows that it is approximately one-half silt, while the remainder is composed almost entirely of very fine sand and clay. Weaver has shown that in this soil-type roots of species common to both true and subclimax prairie penetrate more deeply than in the stiffer silt loam at Lincoln (1919:15). Normally, the rainfall is about 5 inches greater than at Lincoln; however, during 1921 it was not only deficient, but also poorly distributed. During April, the rainfall was nearly 3 inches below normal, 70 per cent of it falling at one time. For May it was 1.6 inches below normal, 72 per cent of it falling between May 7 and 10. June, with 3.4 inches of precipitation, practically all of which occurred before the middle of the month, had a deficiency of 1.4 inches. The holard was much below normal and the poor growth of crops marked the season as one of distinct drought (Weaver, Jean, and Crist, 1922:78), though the native species made a fairly good growth. When they had reached an age of 90 days (July 18–19), the development of the plants both above and below ground was recorded (table 28). The development below ground was marked and agreed well with previous findings as to the deep-seated nature of mature root systems in this mellow loess soil.

Seedling Transplants.

Seedlings of 14 species were transplanted to the gravel-knoll on May 9. *Agropyrum glaucum*, *Aristida purpurea*, and *Stipa viridula* had died by May 25, *Elymus canadensis* and *Koeleria cristata* succumbed early in June, and

Bouteloua racemosa and *Stipa comata* later in the month. *Liatris punctata* and *Stipa spartea* died in July and *Andropogon furcatus* in August. By the end of the summer *Bouteloua gracilis* and *Liatris scariosa* were represented by remnants only, and both species died later in the year. *Bouteloua hirsuta* came through the summer with only one small clump about 3 inches tall and *Andropogon nutans* with two, 6 or 7 inches high, the survival for the first season being 14 per cent.

TABLE 28.—*Development of seedlings at Peru, Nebraska, July 19, 1921.*

Species planted Apr. 19.	Development of shoots.	Working depth of roots.	Maximum depth of roots.	Lateral spread of roots.
		in.	*in.*	*in.*
Andropogon nutans..	Good stand; luxuriant growth; ave. height 11 in.; max. height 16 in.	36	48	..
Aristida purpurea...	Good growth; height 4 to 6 in.; 12 to 30 tillers per plant.	26	41	..
Bouteloua gracilis...	Good stand; lvs. 4 to 8 in. high; exceedingly well tillered; flower-stalks about 9 in. tall.	22	37	8
Elymus canadensis..	Vigorous plants; height 10 to 16 in.; 3 to 4 tillers per plant; heads appearing.	27	42	9
Liatris punctata.....	Good growth; 3 to 5 leaves per plant; 3 to 4 in. tall.	..	47	..
Stipa viridula.......	Thin stand, vigorous growth, ave. height 7 to 9 in.; 6 to 10 tillers per plant.	18	26	12

Seedlings that were transplanted to low prairie at the same time made a much better growth. All grew well, but by the end of June *Agropyrum*, *Bouteloua racemosa*, and *Elymus* particularly, showed the effects of shading. In July, through error, a part of the prairie into which the transplant area extended was mown. Those in the area of better illumination made a fine growth, the shorter boutelouas reaching heights of 4 to 8 inches and the andropogons 6 to 12 inches. In the shaded area *Agropyrum* died and the other species made but a poor to fair growth, the leaves being thin and attenuated; the loss of only 1 of the 13 species is remarkable.

All of the seedling transplants at Nebraska City did very well until about the middle of June, when *Agropyrum*, *Koeleria*, and *Liatris punctata* died and by July 15, *Bouteloua racemosa* had likewise succumbed. The other boutelouas, *Aristida*, and the andropogons, however, were in a flourishing condition. *Elymus*, *Stipa comata*, and *S. viridula* had been badly eaten back by grasshoppers and were represented by remnants only, as were also *Liatris scariosa* and *S. spartea*. *Elymus* and *Stipa viridula* died in August, and *S. comata* was found to be in very poor condition in the autumn, but the other 7 species were doing quite well.

SUMMARY.

A summary of the experiments for this year is given in table 29. The results from the Colorado Springs station are omitted because the area was broken into by cattle and closely grazed. Owing to the drought at Nebraska City, the percentage of germination is lower here than in low prairie at Lin-

coln. However, the percentage of establishment averaged slightly higher at the Nebraska City station, although growth was somewhat poorer. The germination averaged slightly lower on the gravel-knoll (where surface sowing was omitted) than at Nebraska City, while the establishment was decidedly

TABLE 29.—*Summary of sowing experiments, 1921.*

Method of planting.	Percentage of germination.			Percentage of germinated species established.		
	Gravel-knoll.	Low prairie.	Nebraska City.	Gravel-knoll.	Low prairie.	Nebraska City.
Surface	..	78	78	..	14	29
Trench	55	75	50	17	17	33
Denuded quadrat	71	75	68	40	83	60
Average	63	76	65	29	38	41
Seedlings	..	..	..	14	92	57

lower. The survival of transplanted seedlings was highest on low prairie (92 per cent), intermediate at Nebraska City (57 per cent), and least on the gravel-knoll (14 per cent).

Of the survivors of the surface-sown species of the preceding year (1920) on low prairie, *Koeleria* was winterkilled. One of the 4 survivors at Nebraska City died. Of those sown in the trench, both survivors of 1920 on the gravel-knoll died, 2 of the 4 on low prairie, and 3 of the 6 at Nebraska City. Among the species planted in the denuded quadrats during 1920, none persisted on the gravel-knoll. One of the 10 survivors on the low prairie died during 1921, and also 1 of the 10 at Nebraska City.

TABLE 30.—*Comparison of germination and growth at the several stations, 1921.*

Average per cent of germination.		Average per cent of establishment of germinated species.	
Lincoln high prairie	81	Phillipsburg	65
Lincoln low prairie	76	Nebraska City	41
Phillipsburg	68	Lincoln high prairie	40
Nebraska City	65	Lincoln low prairie	38
Lincoln gravel-knoll	63	Gravel-knoll	29
Burlington	43	Burlington	7
Per cent of establishment in denuded quadrats:		Per cent of establishment of seedlings:	
Lincoln low prairie	83	Lincoln, low prairie	92
Lincoln high prairie	65	Phillipsburg	75
Phillipsburg	63	Nebraska City	57
Nebraska City	60	Lincoln, high prairie	54
Gravel-knoll	40	Gravel-knoll	14
Burlington	21	Burlington	0

If the data from the other stations are included and arranged in the order of the average percentage of germination (table 30), they prove to be in general agreement with those of the preceding year (p. 48), with two exceptions. Owing to the drought, Nebraska City ranks after Phillipsburg, instead of heading the list, while Phillipsburg falls behind low prairie in rank.

When the stations are arranged according to the average percentage of establishment, Phillipsburg ranks highest with 65 per cent (largely because

of the excellent establishment of surface-sown plants). The Lincoln stations and Nebraska City are about the same (38 to 41 per cent), while the gravel-knoll and Burlington have changed in relative position, the latter giving the lowest percentage of establishment. On the basis of establishment in denuded quadrats, the same sequence occurs as during 1920, except that Nebraska City then ranked first and the gravel-knoll last. If an average is obtained from all four criteria for growth, the stations aline themselves as follows: Low prairie 72, Phillipsburg 67, high prairie 60, Nebraska City 56, gravel-knoll 37, and Burlington 18.

Sod Transplants.

Gravel-knoll.

Between March 20 and 31, 18 blocks of sod, including 14 species from the various Lincoln stations, were transplanted to the gravel-knoll. *Distichlis spicata* died in June, while *Agropyrum glaucum, Andropogon scoparius,* and two lots of *Koeleria cristata* died during August, notwithstanding the relatively favorable season for growth. With the exception of *Poa pratensis,* all of the other species made a fair growth, but the scarcity of water was indicated by the rolling of leaves and frequent wilting (table 25). *Andropogon furcatus* and *A. nutans* reached a height of a foot and *Panicum virgatum* one of 1.5 feet, but did not put forth flower-stalks. *Bouteloua hirsuta* and *racemosa* had a few flower-stalks each at 1 and 2 feet respectively, while *Bulbilis* blossomed profusely in June, but like the other species did not increase its area. *Elymus* bore several fine heads at a height of 2 to 2.5 feet and *Spartina cynosuroides* from the swamp flowered at 27 to 34 inches; *Poa* and *Stipa* also blossomed.

Poa and both clumps of *B. racemosa* were winterkilled. *Elymus* died during the August drought, but all of the others made a fair to good growth, although adversely affected by the late summer drought. Seven of the 8 species bloomed, *Andropogon furcatus* from the low prairie alone failing to put forth flower-stalks. All survived the drought of the following fall and winter. *Panicum* alone made a poor growth the following season, while *Andropogon furcatus, Bulbilis,* and *Spartina* spread a foot or more beyond their original area. By August 25, *Stipa* and *Bulbilis* were the only species that gave signs of having flowered or preparing to flower, a striking contrast to the preceding year, when drought promoted reproduction. Even during the very favorable year of 1923, but more especially during preceding seasons, sod transplants on the gravel-knoll were all much shorter than elsewhere. They also began renewed development earlier and produced flower-stalks sooner.

Of the species planted in the spring of 1920, although suffering severely from drought, only one sod of *Poa* and another of *Andropogon scoparius* in the unwatered row died (table 66). One of *Koeleria* was winterkilled, while a sod of *Elymus* and another of *Koeleria* died during August of the second season. Practically all of the species, including *Panicum virgatum* and *Spartina cynosuroides,* made a fair growth, rolling of leaves and wilting occurring much more rarely than in transplants of the current year, owing to the well-established root systems. Exceptions to this occurred in the case of *Agropyrum,* both lots of which did very poorly, as did also one sod of *Elymus* and the remaining block of *Koeleria*. After the middle of August, when the

short-grass cover of the knoll began to dry, most of the tall-grass sods began to change color and enter the winter condition also. One lot each of *A. furcatus*, *A. scoparius*, *B. racemosa*, *Elymus canadensis*, and *Poa pratensis* and all three lots of *Panicum virgatum* had flowered and set seed, although the flower-stalks were fewer in number and smaller than normal. Of the species that seeded the first season after transplanting, viz, *Koeleria*, *Stipa*, *Agropyrum*, *Elymus*, *Panicum*, and *Poa*, only the last three seeded the second year. The single remaining lot of *Koeleria* and *Poa* were both winterkilled and one *Agropyrum* died in June 1922. Both lots of *Elymus* died later in the summer, as did also one of *Andropogon furcatus*. The effect of drought upon the other species is shown in table 66. So well were these species rooted, however, that the dry fall and winter of 1922–23 took but a single *Andropogon scoparius*. The growth during 1923 was marked, *Panicum* doubling and *Andropogon nutans* tripling its area.

Low Prairie.

Fifteen species of grasses were transplanted into the low prairie late in March 1921. The rank growth of the native tall-grasses produced a very dense shade (plate 6A). *Bouteloua hirsuta*, *Distichlis spicata*, and *Koeleria cristata* had died by late summer and *Agropyrum* had made but poor growth. *Bouteloua gracilis* and *Bulbilis dactyloides* both reached a height of 12 inches, the leaves being much attenuated, but neither was able to increase its territory. *Andropogon furcatus*, *A. nutans*, *Bouteloua racemosa*, *Spartina cynosuroides*, and *Stipa spartea* all developed about normally, but none blossomed. *Bulbilis*, *Poa*, *Andropogon scoparius*, *Elymus*, and *Panicum* bore well-developed flower-stalks and seeded rather profusely. During the following May and June, owing to the dense cover and resulting competition, *Andropogon scoparius*, *Bouteloua racemosa*, *B. gracilis*, and *Stipa spartea*, all high-prairie species, died. *Bulbilis* died in July, while by the end of the summer *Agropyrum*, one *Elymus*, and *Poa* were represented by remnants only. *Elymus*, *Panicum*, and *Spartina* alone blossomed. All these survived the dry winter, but by August 1923, *Agropyrum* was dead and *Poa* nearly shaded out. Both lots of *Elymus* were heading at 40 to 42 inches high, while the other subclimax species, viz, *Spartina*, *Panicum*, *Andropogon nutans*, and *A. furcatus*, were all flourishing.

As to the 1920 transplants at this station, all made a good growth, and all except *Spartina cynosuroides* bloomed (table 67). By May 18, 1921, *Bouteloua racemosa*, one lot of *Koeleria*, and two of *Stipa spartea* were dead. Many others, particularly *Agropyrum*, *Bulbilis*, *Distichlis*, and *Stipa*, were suffering from shading and invasion, but all other species made a good growth during June and July. By the end of the summer, one *Agropyrum* had died, and the other was much attenuated. *Bulbilis*, *Distichlis*, and *Koeleria* were nearly dead, being represented by remnants only, and *Bulbilis* alone had blossomed. However, all of the other species had made an excellent growth. The three andropogons exhibited abundant flower-stalks 3 to 5 feet high, and *Bouteloua gracilis* had leaves a foot tall, but flowered sparingly. *Elymus* and *Panicum* possessed flower-stalks in profusion 4 to 5 feet tall, and *Stipa* seeded at 33 to 36 inches, while *Spartina* made a good growth but did not blossom.

By May of the following spring (1923), one *Andropogon scoparius* and *Koeleria* had died in addition to *Distichlis*. *Panicum virgatum* and *Andro-*

pogon nutans and one lot of *A. furcatus* were indistinguishable from the general cover. *Poa pratensis* and another *Andropogon scoparius* died in July, and *Agropyrum glaucum* and *Bulbilis* by August. At this time the following were in rather poor condition: one *Andropogon scoparius*, both plants of *Bouteloua gracilis*, and *Elymus* and *Koeleria*, but the rest had made a good growth. By the spring of 1923, *Bouteloua gracilis* and one *Andropogon scoparius* were dead. By the end of this, the fourth season, sufficient time had elapsed for a fair adjustment of the species to the low-prairie habitat. Although the remaining high-prairie species (two lots of *Stipa* and one of *Koeleria*) were still in fair condition, the last *Andropogon scoparius* was in straits. The other species of the subclimax prairie, viz, *Andropogon furcatus*, *Elymus canadensis*, and *Spartina cynosuroides*, were flourishing, while *Andropogon nutans* and *Panicum virgatum* had already become indistinguishable from the native sod. The following had entirely lost out in the struggle for light: *Agropyrum*, *Bouteloua gracilis*, *Bulbilis*, *Poa*, *Bouteloua racemosa*, and *Distichlis spicata*. As a consequence, these experiments clearly reveal the effect of competition in sorting out species and stabilizing vegetation.

Salt-flat.

Sods of each of the preceding species were also transplanted into the salt-flat late in March, 1921. During June most of the plants suffered from drought, great cracks appearing on the sides of the transplanted blocks, owing to the peculiar nature of the soil (p. 44). Growth was very poor, wilting and even dying of parts being not uncommon. Throughout July, growth was slow, most of the sods making only a sparse growth and *Spartina* alone flourishing. *Koeleria* and *Stipa* failed to blossom or bore only a few dwarfed flower-stalks, and the inflorescence of *Bulbilis* was also shorter than normal. By the end of the summer, the leaves of *Andropogon furcatus*, *A. nutans*, and *Bouteloua racemosa* were dying back, while *Panicum virgatum* and *B. hirsuta* were nearly dead. These, like *Agropyrum*, *B. gracilis*, and *Spartina*, had failed to blossom. *Andropogon scoparius*, *Elymus*, and *Poa* had dwarfed flower-stalks and *Distichlis* alone developed normally.

As a result of the drought of the following June, all the sods were in poor condition, large cracks occurring around most of the transplanted blocks, even those that had been transplanted 2 or 3 years, and many of them were very dry. One *Koeleria* died in June and the other two did very poorly. *Poa* and *Panicum* were represented only by remnants at the end of the season and the growth in many of the other blocks was very sparse. Practically all of the plants were dwarfed and only 4 species blossomed, viz, *Andropogon scoparius*, *Bulbilis*, *Elymus*, and *Koeleria;* on these the inflorescences were much dwarfed.

During the very favorable growing-season of 1923, another *Koeleria* and *Stipa* died and *Andropogon furcatus*, *A. scoparius*, *Bouteloua racemosa*, *Panicum virgatum*, and *Spartina cynosuroides* were represented by remnants only. Seven species seeded, although not abundantly.

The sods transplanted into the salt-flat during 1920 made a poor growth the first season, though 8 of the 13 species blossomed (table 68). Compared with the growth of similar species in the adjoining low prairie, nearly all were greatly dwarfed. However, they survived the first season. During May 1921, *Andropogon scoparius*, *A. nutans*, *Stipa spartea*, one lot of *Elymus*

canadensis, and one *Koeleria cristata* were in poor condition or dying. However, many of the others, including *Panicum* and *Spartina*, were doing quite well. Throughout June and July they grew fairly well, except *A. scoparius*, which was mostly dead and badly invaded by *Distichlis*. All lived throughout the second season but *Bouteloua racemosa*, though none grew normally except *Distichlis*. *Agropyrum*, *A. scoparius*, *A. nutans*, *B. racemosa*, *Spartina*, and *Stipa* failed to flower. The dwarfed condition of the remaining species, all of which blossomed, was well represented by *A. furcatus*, which bore flower-stalks only about 2 feet high. *Panicum* was an exception, with a few stalks reaching a height of 40 inches, but its vegetative growth, as for all of the other species, was much below normal. *Elymus canadensis* failed to grow in 1922, while one *Panicum virgatum* died in June. Although the plants in general made a fair growth, they were dwarfed and several species did poorly. *Andropogon furcatus*, *Distichlis*, *Koeleria*, *Panicum*, and *Poa* blossomed. Owing to an excellent holard, all the species except *Elymus*, *Stipa*, and *Andropogon nutans* made a good growth during 1923. Consequently, it seems evident that several species can tolerate the saline areas dominated by *Distichlis* and *Agropyrum*, as was clearly shown during the wet year of 1923. As a result, the salt-basin is being gradually invaded by various prairie species.

Salt-basin.

A similar lot of sods was transplanted to an area in the salt-basin just west of Lincoln, which is dominated by *Dondia depressa*. This halophyte occupies an intermediate zone between the less saline *Distichlis* area and the wetter and more saline one of *Salicornia herbacea*. Repeated analyses of the soil in the *Dondia* area show that it has a salt-content of 1.8 to 2.0 per cent, practically all of which is sodium chloride. The holard in spring and early summer is more or less favorable for growth. *Dondia*, *Salicornia*, and *Distichlis* were also transplanted early in April, together with the sods of the grasses. Within 20 days the transplants from non-alkaline soil began to lose their green color and the tips of the leaves to dry, and after another 20-day period all were dead. The three halophytes did very well throughout the season, except *Salicornia*, which suffered apparently from drought late in the summer.

Swamp.

Sods of the same species were transplanted into the swamp in March 1921. Owing to the building of a dam higher up the ravine, conditions were markedly different from the preceding year. The soil in the wettest area was not saturated to the surface throughout the spring, although water stood on the top during the first week in May. For much of the remainder of the season the area was relatively dry, the holard being so low that water could not be pressed out by hand from the surface 6 inches. The *Poa* zone was also drier than the preceding year. This area, which was nearly pure bluegrass at the beginning of the experiments (1920), was now invaded by a rank growth of *Spartina*, and light conditions were less favorable than formerly.

In the swamp all of the grasses made a very good growth until the end of June, *Bulbilis* flowering profusely, but *Stipa* and *Koeleria*, other early bloom-

ers, failed to bloom. At this time *Spartina* was 3 feet high all around the sods and the transplants began to show the effects of shading, the light values falling as low as 2 to 5 per cent. By the end of July the surrounding vegetation was 4 feet tall and some of the sods were found with difficulty. The soil was wet, and hence many of the plants were slender, with narrow leaves. Late in August, *Agropyrum, Bouteloua hirsuta, B. gracilis, Distichlis,* and *Koeleria* were dying back or mostly dead, some being represented by remnants only. They were all attenuated and none had produced flower-stalks. *Andropogon nutans, A. scoparius, B. racemosa, Spartina,* and *Stipa* had all made excellent growth, but none produced flowers. *Bulbilis, Elymus, Poa,* and *Panicum* also grew well and blossomed about normally.

The sods in the *Poa* zone, which were planted at the same time, made a good growth early in the season. By the end of June, *Spartina, Cyperus, Mentha,* etc., had reached a level of about 3 feet and the shade was dense. *Bulbilis* and *Bouteloua gracilis* both had delicate slender leaves 10 to 14 inches tall, while those of *Koeleria* reached 15 inches. None had blossomed, but *Stipa* had a few fruits which were smaller than normal. On August 31, one-half of *Bouteloua gracilis* was dead and *Distichlis* was nearly so. However, most of the other species, though slender, had made in almost every case a much better growth than in the wetter part of the swamp. Six of the 13 species, viz, *Andropogon scoparius, A. nutans, Stipa, Distichlis, Elymus,* and *Panicum,* blossomed, in contrast to 4 of the 14 species in the swamp.

In 1922, the swamp area was much drier than during preceding years; in fact there was nowhere excess holard or deficient aeration, light being the controlling factor. *Spartina* was over 2.5 feet tall by the middle of June and 4 feet in August, covering the area with a dense growth. Conditions were very similar in the *Poa* zone. The leaves on practically all of the plants were very narrow, long, and delicate, *Andropogon scoparius* did not appear in the spring, and *Koeleria* died in August. The following early bloomers produced flowers: *Bulbilis, Koeleria, Stipa,* and *Poa,* while the subclimax dominants *Elymus* and *Panicum* also blossomed. By June of 1923, *Bouteloua hirsuta, Bulbilis,* and *Distichlis* were dead, while *Bouteloua gracilis, B. racemosa, Elymus,* and *Stipa* vanished later in the summer. This left a few remnants of *Agropyrum* and well-developed plants of *Andropogon nutans, Panicum virgatum,* and *Spartina cynosuroides* at the end of the third season. In the *Poa* zone all survived the 1922 season, but the following species died the next summer: *Andropogon nutans, A. scoparius, Bulbilis, Bouteloua gracilis, Distichlis,* and *Elymus. Agropyrum, Bouteloua racemosa,* and *Stipa spartea* were represented by remnants only, while *Andropogon furcatus, Panicum,* and *Spartina* were the only species that had developed normally.

The fate of the sods planted in the swamp during 1920 is instructive. *A. scoparius, A. furcatus, A. nutans, B. gracilis, B. racemosa, Koeleria,* and *Stipa* died the first season, while many of the others came through in very poor condition (table 69). In May of the following spring *Agropyrum* and *Elymus,* and especially *Poa,* showed signs of distress. *Spartina* developed normally, while *Panicum* and *Distichlis* were in good health. Both *Agropyrum* and *Poa* had died by the end of July; autumn found remnants only of *Distichlis* and *Elymus,* but *Panicum* and *Spartina* had made a good growth and seeded. During 1920, *Koeleria, Stipa, Andropogon scoparius,* and *A. nutans*

died in the *Poa* zone. The following spring *Agropyrum glaucum* and *Bouteloua racemosa* failed to appear, while *B. gracilis* died in June after a feeble growth. *Distichlis* succumbed in August, but *Elymus, Poa, Panicum*, and *Spartina* made a fairly normal growth, all ripening seed.

Since the swamp was much drier and the air-content higher, the chief factor inhibiting growth was not aeration but light (p. 73). *Spartina* became indistinguishable from the surrounding vegetation. *Panicum* blossomed normally, *Elymus* bore a single flower-stalk 2 feet high, while *Distichlis* did very poorly. In the *Poa* zone, *Poa* and *Elymus* made an excellent growth, the former merging into the common sod and the latter flowering at a height of over 4 feet. *Panicum* and *Spartina* developed normally in every way. In 1923 *Distichlis* died, but the three low-prairie species developed very well, the 4 species in the *Poa* zone also prospering. The results are in accord with the expectation, since all the species except those of the mesophytic subclimax prairie, viz, *Andropogon furcatus, Elymus, Panicum*, and *Spartina*, had lost in the struggle during the period of 3 or 4 years.

Regional Transplants.

As to the fate of the sods transplanted to Colorado Springs in 1920, both blocks of *Stipa spartea* had died by the end of 1921, as well as one each of the following species: *Andropogon furcatus, A. scoparius, Bouteloua racemosa, Elymus, Koeleria*, and *Panicum*. This was chiefly due to drought, but partly also to overgrazing, stock having broken into the inclosure at several times. In 1922, *Bulbilis* alone blossomed, repeated grazing again weakening the other plants. By the autumn of 1923, grazing having been continued, the last lot of *Elymus* had died, several of the other species were represented by remnants only, and all were in rather poor condition.

During 1921, sods of *Stipa setigera, S. eminens, Poa tenuifolia*, and *Melica imperfecta* from California were transplanted into high and low prairie respectively on June 23. These were received at Lincoln on May 18, but were kept in a garden and watered frequently before the large blocks of soil containing the transplant were removed to the native grassland. Here they were again watered from time to time as necessary. Only a few made a feeble growth and all on the high prairie were dead by July 30. On the low prairie four lots put out new shoots 3 to 5 inches long, but these died by the end of the summer.

On July 20 the following species from Arizona were transplanted in quadruplicate into a garden at Lincoln and kept well watered: *Bouteloua eriopoda, B. rothrocki, B. bromoides*, and *Aristida divaricata*. All made some growth. In September one clump of *B. eriopoda* bore flower-stalks about 15 inches tall, and one *B. bromoides* possessed leaves 9 inches high and flowered abundantly at 15 to 22 inches.

4. EXPERIMENTS DURING 1922.

PHYSICAL FACTORS.

Rainfall.

The season of 1922 was fairly favorable for growth, except the latter part, when severe drought occurred at all the stations, being relatively less marked at Burlington. At Lincoln the combined precipitation for March and April averaged about normal; that of May and June was approximately 1 and 2 inches below the mean respectively, July had an excess of 2.4 inches, but only 0.7 of the 3.7 normal rainfall of August occurred (fig. 9). At Phillipsburg the April precipitation was nearly 1.5 inches above normal (no report for May), June, July, August, and September showing deficiencies of 2.4, 0.6, 1.8, and 1.6 inches respectively (fig. 15). The Burlington precipitation was about half the normal during March (April report missing), 0.4 inch in excess during May, while June gave an excess of 1.4 inches over the mean. July had a deficiency of 0.8, August an excess of 0.5, and September was also far below the normal (fig. 16). Spring and early summer drought periods, i. e., rainfall less than 0.21 inch, occurred at Lincoln from April 11 to May 8 and May 26 to June 24. At Phillipsburg a 10-day drought occurred in April (May report missing) and no rain fell from June 1 to 26. The severity of the late-summer drought at both Lincoln and Phillipsburg is well illustrated by the fact that by the end of August the late-developing *Andropogons* were already half dried and appeared to be entering the winter condition. No efficient precipitation fell at Burlington from May 2 to 19 and 20 to 29 (April report missing) or June 2 to 15.

Holard.

A study of the water-content (table 31) shows that a margin of 5 per cent (more usually 7 to 11 per cent) above the hygroscopic coefficient existed at all times to a depth of 4 feet in the high prairie at Lincoln (except in the surface 6 inches on June 22).

At the mixed-prairie station a good water-content prevailed to 3 feet in the spring, but the margin of safety was much less at nearly every determination than at Lincoln. Late in June, and again throughout July and August, drought prevailed, no water being available often to depths of 4 feet. Conditions at Burlington were not very different, the soil in spring and early summer being as usual quite moist. However, the deficiencies were very marked and practically continuous after June 18.

Temperature.

Air-temperatures in general were lowest at Burlington, 7° F. higher at Lincoln during early May, and usually 3 to 5° higher during the rest of the season; those at Phillipsburg exceeded those at Lincoln by 2 to 5°, especially after June 7 (fig. 38). The night temperatures at Burlington were decidedly lowest (by 2 to 10°), those at Lincoln intermediate, and at Phillipsburg highest (fig. 39). A similar general relation, but one less marked and with overlappings, holds for the day temperatures. Soil-temperatures at a depth of 3 inches were obtained until the middle of June, after which the thermograph bulbs were buried at a depth of 12 inches and left for the remainder of

the season. In figure 40 it may be seen that the moister soil at Lincoln was also that with the lowest temperature, although the differences, as in the case

Table 31.—*Holard in excess of the hygroscopic coefficient at the several stations, 1922.*

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
Lincoln, Nebraska.					
Apr. 30	15.3	15.8	14.7	10.9	9.1
May 10	10.1	13.7	15.3	....	....
May 17	12.0	13.1	14.1	12.1	7.8
June 7	6.4	11.2	10.9	....	....
June 14	6.8	11.3	10.5	8.4	6.6
June 22	3.5	6.3	11.1	....	....
July 6	5.7	4.7	8.9	8.0	5.4
July 13	17.8	11.7	8.1	....	....
July 20	16.4	10.7	6.2	....	....
July 27	21.2	14.7	7.5	....	....
Aug. 3	8.2	10.1	7.4	8.0	6.0
Aug. 10	5.6	6.2	7.4	....	....
Aug. 17	0.9	1.8	0.8	....	....
Aug. 24	3.2	5.4	5.1	7.1	5.3
Hygroscopic coeff	9.8	10.9	10.1	10.0	10.3
Phillipsburg, Kansas.					
Apr. 28	18.8	19.4	14.1	1.5	1.3
May 19	5.4	10.2	9.3	6.2	0.4
June 11	1.7	9.5	7.8	8.2	0.5
June 17	1.4	4.4	....	....	....
June 24	−1.6	0.9	....	....	....
June 30	10.8	1.1	3.7	5.1	4.7
July 17	−1.7	0.2	−0.5	−0.2	0.9
July 28	−0.1	1.6	....	....	....
Aug. 3	0.5	0.7	−0.5	−0.1	0.0
Aug. 11	−1.5	−1.8	−1.3	....	....
Aug. 17	−3.7	−1.5	....	....	....
Aug. 27	−2.6	−1.4	0.7	−1.7	0.2
Hygroscopic coeff	10.6	10.6	10.9	10.6	10.7
Burlington, Colorado.					
Apr. 30	17.6	16.9	8.5	−1.0	−1.0
May 20	19.8	9.6	8.7	6.8	−0.4
June 4	12.2	10.3	8.3	6.8	....
June 11	−0.1	1.2	4.5	4.9	−1.1
June 18	0.4	1.1	3.8	....	....
June 25	0.2	0.0	1.2	2.1	−0.2
July 2	11.1	−1.8	−2.6	−0.6	−1.3
July 16	−2.5	−1.9	−0.5	0.0	−1.0
July 23	6.7	−1.1	−0.1	1.1	....
July 30	−0.7	−0.7	−0.2	....	....
Aug. 4	5.4	−1.5	−1.9	−0.4	0.6
Aug. 20	−1.7	−1.9	−1.1	−0.2	....
Aug. 26	−0.3	−2.1	−2.7	−1.9	−0.4
Hygroscopic coeff	10.9	10.9	12.2	12.0	11.4

of air-temperatures, are not great enough to be of much importance in the establishment and growth of native vegetation.

Humidity.

Continuous records of humidity were not obtained during 1922, but a comparison of the hygrograph records from Burlington and Lincoln, from which the average day and average night humidities have been obtained, shows striking differences. With few exceptions, the air at the former was

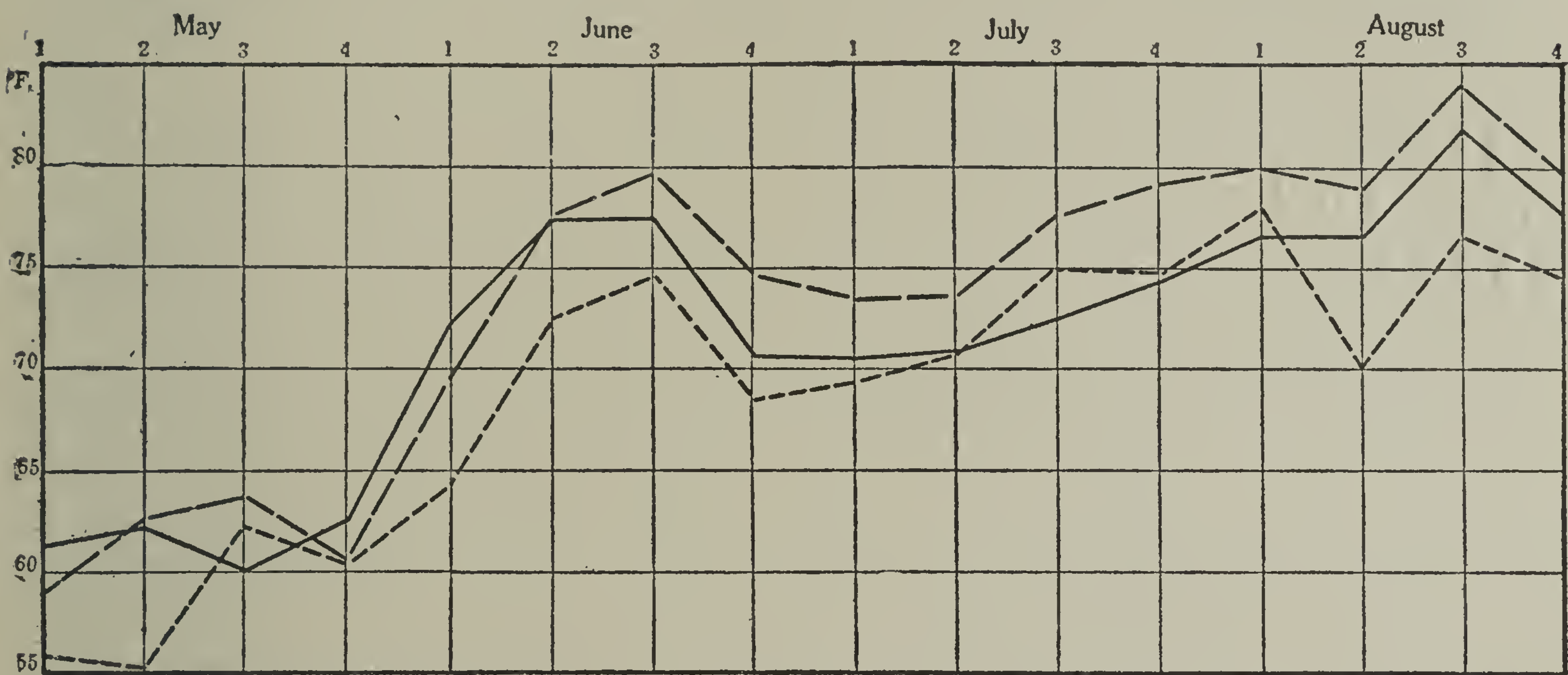

Fig. 38.—Average daily temperatures at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1922.

13 to 25 per cent drier by day (table 32). Owing to the high altitude (4,160 feet) and cool nights at Burlington, differences in night humidites were less marked. Frequent isolated readings at Phillipsburg, when compared with the records at the other stations, showed that they were usually intermediate.

Table 32.—*Average day and night humidites at Lincoln and Burlington, 1922.*

Date	Average day humidities.		Average night humidities.	
	Lincoln.	Burlington.	Lincoln.	Burlington.
	p. ct.	*p. ct.*	*p. ct.*	*p. ct.*
May 1 to 7	44.7	45.5	73.5	77.3
8 14	50.5	26.2	77.5	58.2
15 21	44.5	39.7	70.9	74.5
22 28	77.4	64.5	89.0	87.9
29 to June 4	64.2	....	90.2	....
June 5 to 11	58.3	45.8	87.5	75.4
12 18	60.6	40.5	86.6	74.2
19 25	48.8	37.2	73.2	73.0
26 to July 2	61.4	....	85.3	....
July 3 to 9	60.8	51.0	78.5	82.2
10 16	71.0	....	93.0	....
17 23	70.6	44.5	89.4	78.5
24 30	72.2	46.1	92.3	78.3
31 to Aug. 6	66.0	....	90.2	....
Aug. 7 to 13	55.3	61.0	85.3	90.6
14 20	54.0	42.8	81.0	62.1
21 27	50.2	....	80.0	....
28 30	56.3	....	87.8	....

Evaporation.

The average daily evaporation (fig. 41) shows again the relative xerophytism of the several communities, as well as the periods of stress in June and August, although that at the two western stations remained rather high throughout the growing-season. The evaporation at Lincoln ranged from 9 to 33 c. c., at Phillipsburg 8 to 41 c. c., and at Burlington from 15 to 47 c. c. In general, the losses were higher than for the preceding year (fig. 23).

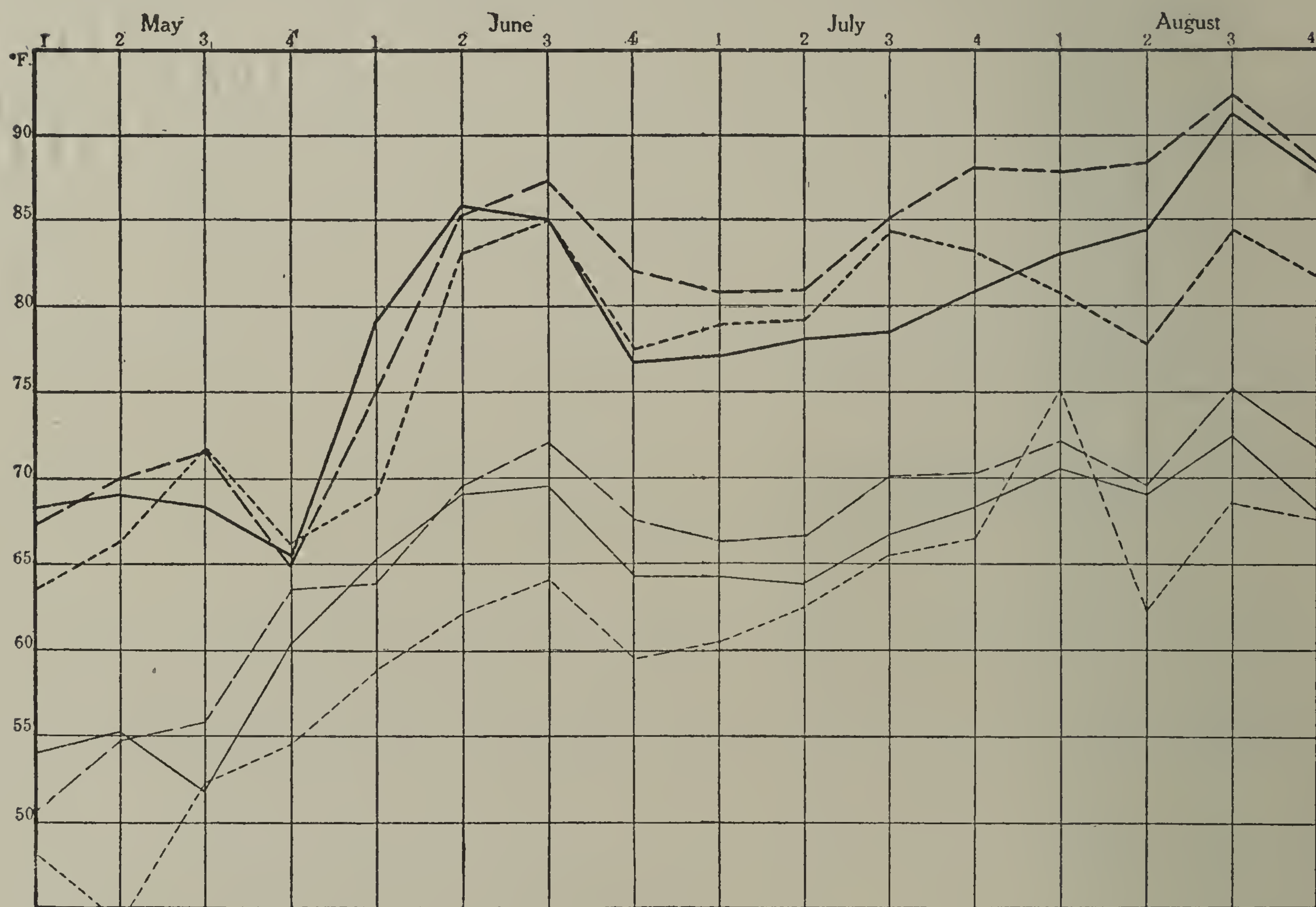

Fig. 39.—Average day (heavy lines) and night temperatures (light lines), at Lincoln (solid line), Phillipsburg (long broken lines) and Burlington (short broken lines), 1922.

To summarize, the season of 1922 was less favorable for growth than 1921, and deficiencies in rainfall and soil moisture were marked, being pronounced even at Lincoln, the least xerophytic of the stations, during late summer. Humidity and holard were again the controlling factors in plant growth, conditions as regards both being progressively more severe westward.

PLANTING RESULTS.

Surface Sowing.

Twenty-two species of grasses, forbs, and trees were planted on the surface of the high prairie at Lincoln on April 18; 82 per cent of the species germinated, only *Aster multiflorus*, *Bouteloua gracilis*, *Solidago missouriensis*, and *Sporobolus asper* failing to do so. However, germination was considerably delayed because of dry weather. All of the species did at least fairly well until July, *Lespedeza*, *Liatris* spp., *Onagra*, and *Pinus* having succumbed by the 14th, while 4 other species were suffering badly. The drought period,

May 26 to June 24, was quite severe. During the latter part the long-established native grasses on the high prairie had rolled leaves and *Erigeron ramosus* was drying, many without flowering. It seems probable that most, if not all, of the surface-sown species would have succumbed except for regular watering. Late August found *Bouteloua hirsuta, Kuhnia, Ratibida,* and *Robinia* added to the mortality list. Thus, the mortality during the first summer was 50 per cent, notwithstanding regular watering at critical periods throughout the season. *Liatris scariosa* died in August 1922, and *Bouteloua hirsuta* did very poorly, but the 5 remaining species flourished, except during the late-summer drought, *Aristida purpurea, Bouteloua racemosa,* and *Elymus canadensis* producing seed. *Andropogon nutans, Bouteloua hirsuta,* and *Bouteloua racemosa* died during the dry fall and winter. During the wet summer of 1923 the shade was very dense. At the end of the season *Elymus canadensis* was represented by a single weak plant; *Liatris punctata,* which was growing in a dense sod, was over a foot tall, but failed to blossom; but *Aristida purpurea,*

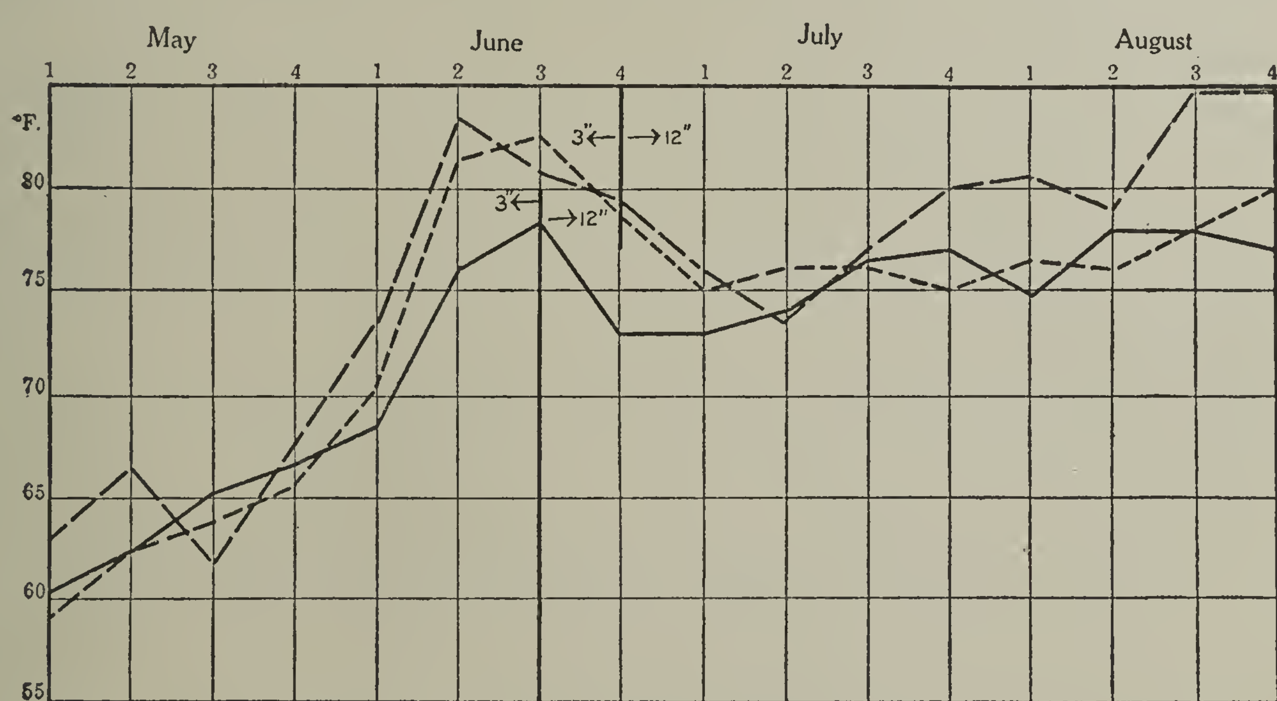

Fig. 40.—Average daily soil temperatures at depths of 3 and 12 inches respectively at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1922.

the other survivor, developed normally and produced an abundance of seed. It seemed only a question of a year or two more, however, until all three would disappear from the stabilized grassland.

Trench Sowing.

Twenty-three of the same species sown on the surface were also planted in a trench on the high prairie at Lincoln on April 18. Seven, viz, *Amorpha canescens, Aster multiflorus, Bouteloua hirsuta, B. gracilis, Onagra biennis, Ratibida columnaris,* and *Solidago missouriensis,* failed to germinate. Of the 70 per cent germinating, *Agropyrum glaucum* and *Liatris punctata* died before the end of the June drought and many others wilted badly. *Lespedeza capitata, Muhlenbergia pungens, Petalostemon candidus,* and *Sporobolus asper* succumbed by the middle of July, while the remaining ten species (63 per cent) lived throughout the summer. Most of them, however, were in poor condition, being badly dried by August 21.

Plants in the trench at Phillipsburg did much more poorly. Of the 23 species planted on April 29 only 8 (35 per cent) germinated. One-half of the trench was rather densely shaded by *Bouteloua racemosa* and *Andropogon furcatus*, and germination in it was very low. Only about half of those that germinated did so abundantly. *Liatris scariosa* and *Sporobolus asper* died by June 30, and *Agropyrum glaucum* in July, while *Elymus canadensis*, *Desmodium canescens*, and *Kuhnia glutinosa* succumbed in August. *Andropogon nutans* and *Bouteloua racemosa* were the only ones that survived the first summer. Although the prairie had been burned over the preceding winter through accident, by May 27 the general level of the grasses had reached 5 or 6 inches, while an upper story of *Psoralea*, *Helianthus*, *Erigeron*, and flower-stalks of *Poa* and *Stipa* at 15 to 22 inches added to the shade. Consequently, light early became an important factor.

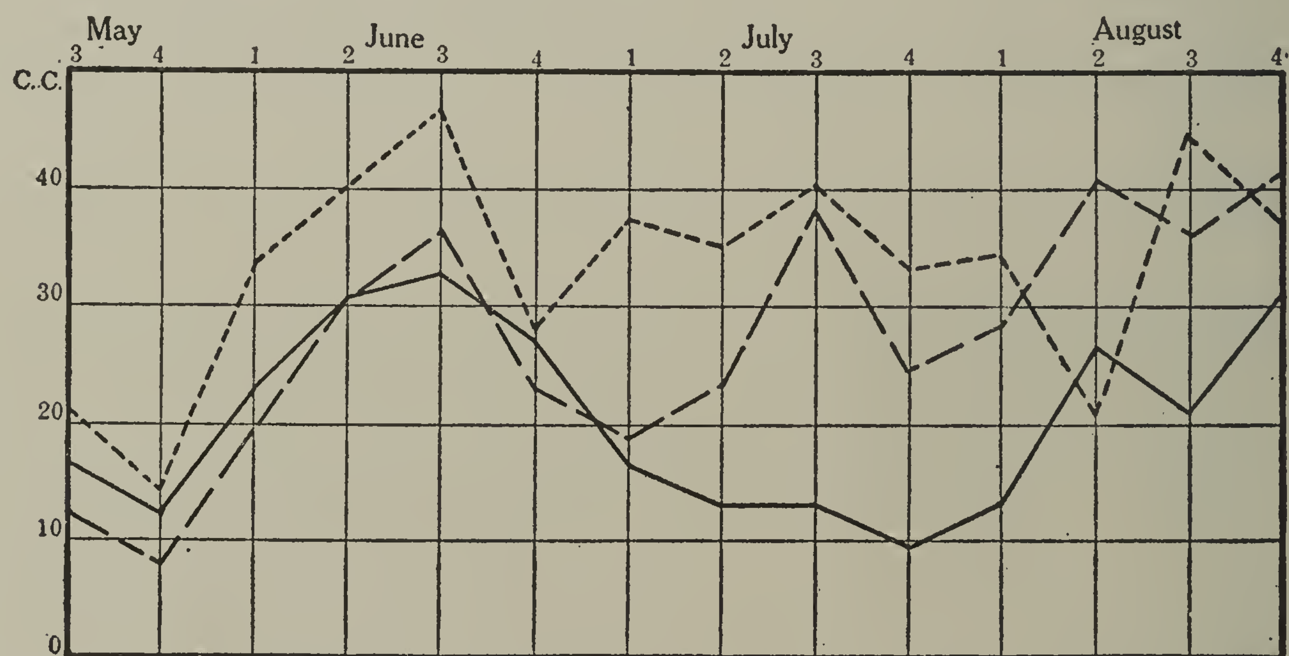

FIG. 41.—Average daily evaporation at Lincoln (solid line), Phillipsburg (long broken lines), and Burlington (short broken lines), 1922.

Twenty-two species were sown on the surface of the mixed prairie at Phillipsburg on April 29, the spring being late at all stations. Of these, 14 per cent, including *Aster multiflorus*, *Lespedeza capitata*, and *Solidago missouriensis*, failed to germinate. By June 30 (no efficient rain having fallen during June 1 to 26), 4 forbs, *Pinus*, and *Sporobolus* had succumbed. On August 3, *Agropyrum* was found dead, and by the last of the month *Amorpha*, *Aristida*, *Petalostemon*, and *Ratibida* had also succumbed. This left 8 species (42 per cent) surviving, of which at least 4 were in very poor condition. Shading was an important factor. As early as June 30 the grass-level was 8 to 14 inches high, with subdominant herbs such as *Psoralea* at a level of 24 inches.

Twenty of the same species grown at Lincoln and Phillipsburg were also sown on the surface of the short-grass sod at Burlington on April 30. Ten species (50 per cent) failed of germination. In fact, only *Andropogon nutans*, *Robinia pseudacacia*, *Desmodium canescens*, and *Liatris scariosa* germinated at all abundantly. Some species lay dormant until late in June, being stimulated to grow by a heavy shower. By the middle of July only one plant of *Liatris scariosa* remained alive, and it succumbed later. The following species alone survived in both the true and mixed prairies: *Andropogon furcatus*, *A. nutans*, *Bouteloua racemosa*, *Desmodium canescens*, and *Elymus*

canadensis. Shading played a minor rôle at Burlington, except in protecting the plants from too rapid water-loss, since the short-grass sod was only 3 inches tall by July 1. The fate of the surface sowing of 1921 is of interest here. At Lincoln 9 per cent survived, but none at Burlington, while, owing to opportune showers and to a much more favorable light relation at Phillipsburg than at Lincoln, 83 per cent survived the first season. Establishment and growth in the mixed prairie, however, were better than on the short-grass plains. Among 22 species planted in the trench at Burlington on April 30, 68 per cent failed of germination. However, 5 of the 6 species that grew germinated rather abundantly. *Robinia pseudacacia*, *Desmodium canescens*, and *Kuhnia glutinosa* died by the middle of July, and *Agropyrum glaucum* in August, while 5 plants of *Andropogon nutans* alone survived the summer. *Andropogon nutans* was the only species that survived at all three stations, reaching a height of 1 to 3 inches at Burlington, 5 to 8 inches at Phillipsburg, and 5 to 9 inches at Lincoln. *Bouteloua racemosa* survived at Phillipsburg and Lincoln, and 8 other species at Lincoln alone.

As to the 1921 trench plantings, the best results were obtained at Lincoln, where 5 of the 11 species that germinated survived the first season. *Bouteloua gracilis* died the following June, but the rest made fair to good growth. During the favorable season of 1923 growth was excellent, *Andropogon nutans* and *Sporobolus asper* reaching heights of 8 to 10 inches, while *Bouteloua hirsuta* and *Liatris scariosa* were 5 to 7 inches tall, but none flowered.

Of the 6 species that started growth at Phillipsburg, only *Andropogon nutans* and *Aristida purpurea* became permanently established. Both did quite well during 1922, but *Andropogon*, which was densely shaded, died in late summer. *Aristida* was represented in 1923 by a small clump which blossomed profusely at a height of 22 inches. No species planted in the trench in 1921 survived at Burlington.

Denuded Quadrats.

Thirty-five species of grasses, forbs, shrubs, and trees were planted in denuded quadrats in the true prairie on April 18. Among these, ten (29 per cent) failed to germinate. *Brauneria pallida* died early in June and *Acer negundo* before the June drought was broken. During this period many other species were wilted or drying. By the middle of July, *Agropyrum*, *Elymus*, and *Ulmus* had also died, while *Andropogon halli* and *Calamovilfa longifolia* were added to the mortality list by August 22. However, 18 species or 72 per cent survived the first summer, the list including trees and forbs as well as grasses. Many of these were seriously affected by drought.

Of 32 species planted on April 29 in denuded quadrats in the mixed prairie, 10 (31 per cent) failed of germination. By June 10, *Lespedeza* and *Liatris scariosa* had died, and *Agropyrum*, *Muhlenbergia*, and *Ulmus* disappeared by the end of the month. *Robinia* dried out during July and *Acer negundo* early in August. The end of August found *Desmodium*, *Elymus*, *Onagra*, and *Pinus* added to the list of non-survivors. This left 11 species, 50 per cent of those which germinated, that survived the first summer. As usual, most of these showed by dead leaf-tips, rolled leaf-blades, or browning, the effects of intermittent periods of drought.

Twenty-eight species were sown in denuded quadrats at Burlington on April 30; 50 per cent of them failed of germination. Among these were *Amorpha, Aster, Liatris, Ratibida, Redfieldia,* and *Solidago,* all of which had also failed at Lincoln and Phillipsburg, notwithstanding they showed fair to good germination in the greenhouse as well as under other methods of planting. Seeds of certain species kept on germinating until July. By this time *Acer saccharinum* and *Andropogon furcatus* had died, but no further losses were recorded until August, when *Agropyrum* and *Robinia* also succumbed. In fact, except for the death of *Aristida,* no further loss of an entire species occurred, although many plants were eaten off by grasshoppers, badly wilted, or entirely destroyed by drought. Thus, 64 per cent survived, showing at once the better conditions furnished by this method as compared with that of surface or trench sowing. The surface of the soil in these quadrats, as was true of those 2 or 3 years older, was always mellow; *Bulbilis* had started to invade the older ones from all sides, but the invasion was very incomplete, even on areas denuded for over 2 years. While the grama in the buffalo-grass sod was flowering rather sparsely at 6 to 12 inches, that around the edges of the quadrats, owing to an increased holard due to lessened competition, was 6 to 20 inches tall.

Summary.

Andropogon nutans, Bouteloua gracilis, Bouteloua racemosa, Gleditsia triacanthus, Kuhnia glutinosa, and *Panicum virgatum* grew throughout the summer at all three stations. The following survived the summer at two: *Desmodium canescens, Muhlenbergia pungens* (Burlington and Lincoln), and *Acer saccharinum, Andropogon furcatus, Aristida purpurea, Petalostemon candidus,* and *Sporobolus asper* (Phillipsburg and Lincoln). *Andropogon scoparius, Liatris punctata, Onagra biennis, Pinus ponderosa,* and *Robinia pseudacacia* survived only at Lincoln.

A comparison of the results shows that *Bouteloua gracilis* made the best growth at Burlington (5 to 13 inches) and the poorest at Lincoln (2 to 5 inches). *Gleditsia* grew poorest at Burlington (2 to 5 inches) and about the same at the other stations (3 to 7 inches). However, all of the others, *Andropogon nutans, Bouteloua racemosa, Kuhnia glutinosa,* and *Panicum virgatum,* showed the best growth at Lincoln (4 to 12 inches), intermediate at Phillipsburg (3 to 9 inches), and least at Burlington (1 to 5 inches).

The fate of the species planted in quadrats in 1921 is of interest here. At Lincoln, 13 of the 20 species that germinated survived the first season, but the following spring 7 of these failed to come up. The 6 remaining species did very well throughout the next summer, but none came into blossom. In 1923, *Andropogon nutans* formed a dense sod; *Gleditsia* was represented by a single remnant, and *Stipa spartea* by a scattered growth. The other species did fairly well, but all were much shaded and none produced seed. At Phillipsburg, 19 species germinated and 13 survived the first summer; 6 of these, including 4 species of trees, were winterkilled, and *Stipa setigera* died by the end of 1922. *Agropyrum* and both species of *Symphoricarpus* did but poorly; *Andropogon nutans* formed a dense sod, while *Aristida* and *Elymus* both ripened seed. Of the 19 species which germinated

at Burlington in 1921, only 4 survived the first summer. *Gleditsia* was winterkilled and *Calamovilfa* was accidentally destroyed. *Andropogon nutans* grew well during both 1922 and 1923 and reached a height of 6 to 9 inches, but *Bulbilis* had invaded rather extensively. *Stipa viridula* died during the severe winter of 1922–23.

Seedling Transplants.

Seedlings of 20 species were transplanted into the high prairie on May 17 and watered freely from time to time, as weather conditions demanded, until August 23. Notwithstanding this aid to establishment, *Aristida purpurea* and *Petalostemon candidus* died early in June, *Agropyrum glaucum* and *Solidago missouriensis* in July, and *Psoralea tenuiflora floribunda* and *Stipa viridula* following the drought in August. Several other species were represented by mere remnants, 14 (70 per cent) surviving the summer. As sometimes happens under cultivation, *Onagra biennis* grew a flower-stalk the first season, but failed to blossom and died in the fall.

On May 19, seedlings of 19 species were transplanted into the mixed prairie at Phillipsburg. As at the other stations, they were about 15 days old. In planting, water was placed in the bottom of the trench and after it had settled down, moist soil was added around each root-mass until the trench was two-thirds filled, when a second watering was given. The trench was then filled with drier soil and finally covered with a dry mulch. At all stations the plants were watered for about a week thereafter. *Agropyrum, Bouteloua racemosa*, and *Stipa viridula* died during the June drought, and *Psoralea* by the first of August, but all the others made a good growth, the grasses tillering freely and *Bouteloua gracilis* and *B. hirsuta* blossoming. The mortality was only 22 per cent.

Seedlings at Burlington did very poorly. Of the 19 species planted here on May 20, only 5 survived, 74 per cent succumbing to the unfavorable conditions of the short-grass plains; 1 died early in June, 5 more by July 2, 7 others before the first week in August, and another later in the same month. On August 26, wilted or half-dead clumps of *Bouteloua racemosa, Stipa viridula*, and *Sporobolus asper*, and better lots of *Bouteloua hirsuta* and *B. gracilis*, 2 to 3 inches tall, alone remained. The history was one of repeated wilting and revival only to wilt again, the conditions causing transpiration at this station often being so severe that vegetation wilted even in soil of good water-content. Under such conditions growth was poor. Only three species survived at all the stations, viz, *Bouteloua gracilis, B. hirsuta*, and *Sporobolus asper*, even under this favorable method of transplanting.

As to the 1921 seedlings, 6 of the 13 species transplanted into high prairie at Lincoln died the first summer, while 2 more were winterkilled (table 61). The 5 remaining species grew throughout 1922, all surviving the drought. However, *Andropogon nutans* and *Stipa spartea* died the following winter, leaving only the three species of *Bouteloua*. All these made a good growth in 1923, forming five clumps 5 to 8 inches tall.

At Phillipsburg, 9 of the 12 species survived the first season and 1 died the following winter (table 62). At the end of 1922 *Liatris scariosa* had died and *Agropyrum* and *Andropogon nutans* were doing very poorly. The rest made a good growth, *Bouteloua hirsuta* alone producing flower-stalks. *Andro-*

pogon nutans and *Agropyrum* died the following winter. The two shorter gramas both made a good growth in 1923 and produced seed. *Andropogon furcatus* was densely shaded and did only fairly well; *Stipa spartea* was represented by a few narrow, densely shaded leaves only, while *Liatris punctata* had 5 fine plants about a foot high that blossomed profusely. None of the 1921 seedlings at Burlington survived the first season.

SUMMARY.

The average germination under all methods of planting was similar to that of the two preceding years, Lincoln being highest (74 per cent), the mixed-prairie station second (63 per cent), and the short-grass plains last (44 per cent). However, as regards surface sowing, Phillipsburg ranks slightly ahead of Lincoln, and this in spite of frequent watering at the latter station. The explanation for this seems to lie in soil structure, that at Phillipsburg being much mellower, and hence it does not crust when alternately wet and dry.

TABLE 33.—*Summary of planting experiments, 1922.*

Method of planting.	Per cent of germination.			Per cent of establishment of germinated species.		
	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.
Surface sowing......	82	86	50	50	42	0
Trench............	70	35	32	63	25	14
Denuded quadrats...	71	69	50	72	50	64
Average........	74	63	44	62	39	26
Seedlings..........	....	....	....	70	78	26

This probably accounts for the 8 per cent margin in favor of the seedling transplants, since in all cases the percentage of germination falls off to the westward.

Sixty-two per cent of the species that germinated at Lincoln became established, 39 per cent at Phillipsburg, and only 26 per cent at Burlington. The same sequence held for all methods of planting, except that establishment in the quadrats at Burlington exceeded by 14 per cent that at Phillipsburg. Both the lowest percentage of germination and establishment occurred in the trench, the denuded quadrats ranking highest in percentage of establishment.

SOD TRANSPLANTS.

Large blocks of soil containing 26 species of grasses and forbs were transplanted into high prairie at Lincoln March 22 to April 5. All the transplants made a good growth except *Psoralea tenuiflora floribunda*, which died before the middle of June, probably because of the cutting of its deep tap-root, *Silphium integrifolium*, which succumbed by the end of August, and *Andropogon scoparius* which grew poorly. In addition to 10 of the grasses, the following forbs blossomed and set seed: *Anemone cylindrica, Brauneria pallida, Grindelia squarrosa, Liatris scariosa, Solidago missouriensis, S. rigida*, and *Vernonia fasciculata;* only 7 per cent of the entire lot died.

Eighteen blocks of sod, representing 13 species of grasses, were transplanted from Lincoln into the short-grass sod at Burlington on April 15. Although none died, the growth was with few exceptions rather poor, being characterized by scattered shoots, frequently with rolled leaves and dead leaf-tips. Flowers were present in 61 per cent as compared with 67 per cent of the grasses transplanted at Lincoln. In all cases, however, the flower-stalks were 3 to 10 inches shorter and usually few in number, while the inflorescence itself was dwarfed. For example, *Agropyrum* headed at Burlington at 11 inches, while at Lincoln the flower-stalks were 21 to 27 inches tall; *Elymus* headed at 12 to 18 inches in the Great Plains, but in the true prairie at 28 inches. The vegetative growth was proportionately dwarfed.

EXPERIMENTS AT OTHER STATIONS, 1922.

Physical Factors.

Water Relations.

Studies were continued during 1922 at the series of edaphic stations at Lincoln, and at Nebraska City and Colorado Springs. The general conditions of precipitation at Lincoln have already been given. The season at Nebraska City was one marked by June and August drought. April precipitation was nearly normal, May showed a deficiency of 1 inch, June of 2.6 inches, and, although July had an excess of 3 inches, August had a rainfall of only 0.7 inch instead of the normal 3 inches (fig. 18). Drought periods occurred on April 11 to 30, May 6 to 20, May 25 to June 10, and June 11 to 25. The water-content in excess of the hygroscopic coefficient at Nebraska City and Lincoln low prairie is given in table 34, where that of the high prairie is added for purposes of comparison. A study of the table shows that notwithstanding the decreased rainfall, the soil at Nebraska City usually had a margin of at least 8 per cent chresard below the first foot of soil. Exceptions to this occurred after the first week in June and again in August. However, the chresard in the surface foot, which most critically affects seedlings, was practically exhausted on June 17, and was very low on August 17, as well as at certain other periods. As a whole, the holard was less favorable than during 1921.

Water-content on the low prairie was more favorable than that at Nebraska City and considerably in excess of that on the high prairie. At no time was there a margin of less than 7 per cent available at any level, and it was usually 10 to 12 per cent. Conditions on the gravel-knoll were much less favorable than during the preceding year, as was evidenced by the drying of the grama grasses during a drought when no water was available in the first 2 feet of soil.

The average daily evaporation at Nebraska City was considerably lower than on the high prairie at Lincoln. During the 4 months (last half of May, June, July, and August) the average daily rates were as follows: 12.4 and 15.1, 18.4 and 29, 12.7 and 13.5, 14.4 and 20.2 c. c. respectively. Isolated humidity readings taken from time to time and compared with the hygrograph record at Lincoln for the same hour showed conditions not greatly different from from those of the preceding year.

Table 34.—*Holard in excess of hygroscopic coefficient in 1922.*

Date.	0 to 0.5 foot.	0.5 to 1 foot.	1 to 2 feet.	2 to 3 feet.	3 to 4 feet.
HIGH PRAIRIE.					
Apr. 30	15.3	15.8	14.7	10.9	9.1
May 10	10.1	13.7	15.3	....	....
May 17	20.0	13.1	14.1	12.1	7.8
June 7	6.4	11.2	10.9	....	....
June 14	6.8	11.3	10.5	8.4	6.6
June 22	3.5	6.3	11.1	....	....
July 6	5.7	4.7	8.9	8.0	5.4
July 13	17.8	11.7	8.1	....	....
July 20	16.4	10.7	6.2	....	....
July 27	21.2	14.7	7.5	....	....
Aug. 3	8.2	10.1	7.4	8.0	6.0
Aug. 10	5.6	6.2	7.4	....	....
Aug. 17	0.9	1.8	0.8	....	....
Aug. 24	3.2	5.4	5.1	7.1	5.3
Hygroscopic coeff	9.8	10.9	10.1	10.0	10.3
LOW PRAIRIE.					
Apr. 30	18.4	10.4	20.6	12.5	18.2
May 17	13.4	16.1	17.0	17.0	17.6
May 31	26.7	21.3	18.7	....	....
June 7	13.2	14.6	15.2	....	....
June 14	10.7	13.8	15.1	13.8	19.0
June 22	6.9	9.4	15.4	....	....
June 29	21.9	10.2	11.0	....	....
July 6	13.4	8.0	6.8	12.8	16.6
July 13	28.1	16.8	11.5	....	....
July 20	26.3	21.1	11.2	....	....
July 27	30.6	28.7	15.3	....	....
Aug. 3	17.5	14.6	11.8	11.1	15.9
Aug. 10	10.2	15.8	13.7	....	....
Aug. 17	7.9	9.8	11.0	....	....
Aug. 24	7.8	6.8	11.1	11.8	15.9
Hygroscopic coeff	10.0	9.6	9.2	11.1	10.8
NEBRASKA CITY.					
Apr. 22	17.9	19.3	18.3	15.0	13.3
May 13	8.7	16.2	17.4	14.4	13.2
May 20	4.4	11.0	16.1	....	....
June 3	18.4	18.8	17.0	15.0	14.3
June 10	4.3	9.4	12.3	....	....
June 17	−0.3	1.5	7.9	11.2	....
June 21	2.0	4.2	10.4	10.3	10.2
June 28	4.4	0.8	5.0	12.2	11.8
July 5	8.5	0.9	5.9	....	....
July 12	25.6	21.6	17.7	10.2	10.3
July 19	7.6	13.4	9.9	....	....
July 26	5.5	10.3	9.1	....	....
Aug. 1	18.2	16.3	13.1	9.9	9.5
Aug. 8	11.9	12.7	10.4	....	....
Aug. 15	1.5	6.1	7.8	....	....
Aug. 22	11.2	7.1	4.1	....	....
Aug. 31	3.7	4.8	6.8	8.0	3.4
Hygroscopic coeff	12.1	11.7	12.3	13.6	12.9

Planting Results.

Surface Sowing.

Of typical grasses and forbs, 19 species were sown on the surface of the low prairie on April 20, 1922; unlike the high prairie and gravel-knoll, this area had not been burned. A dense tangle of grass-leaves and flower-stalks covered the ground and formed a loose mulch to a depth varying from 2 to 4 inches. This not only greatly affected the light relations, but also the air was of much higher humidity and lower temperature below the mulch, and the soil was cooler. For example, at 2 p. m. on a clear day (May 28) an average of four thermometer readings at a depth of an inch under the mulch gave a temperature of 68° F., while that at a similar depth in denuded quadrats was 95° F.

Under these conditions the plants germinated slowly, *Desmodium canescens, Liatris punctata* and *scariosa*, and *Petalostemon candidus* alone appearing above ground by May 17. Moreover, by May 26 the new growth of the dominants was 10 to 15 inches tall, so that light relations played an exceedingly important rôle from the first. However, only 3 species, *Aster multiflorus, Ratibida columnaris*, and *Solidago missouriensis*, failed to germinate. Weak plants of *Amorpha canescens, Onagra biennis*, and *Sporobolus asper* lasted only until the middle of June, and *Kuhnia glutinosa, Liatris scariosa* and *punctata*, and *Lespedeza capitata* died within the next 30 days, all showing the effects of shading. *Bouteloua hirsuta* succumbed by August and *B. gracilis, B. racemosa, Desmodium canescens*, and *Elymus canadensis* during this month. This left remnants of *Aristida purpurea* and *Andropogon nutans*, as well as rather good growths of *Andropogon furcatus* and *Petalostemon candidus*. The total mortality was 75 per cent during the first summer. The severe competition for light on the low prairie was chiefly responsible for this; by June 7 the surface and trench plantings were already badly shaded, while by June 22 the general grass level was 18 inches; by September 1, that of the foliage reached over 2 feet and the flower-stalks 43 inches. In the part of the area unmown since 1919, growth was even greater.

On the surface at Nebraska City, 20 species were sown on April 22. Spring opened late and the soil was in excellent condition as regards holard. Nine species were above ground by May 13. *Aster multiflorus, Bouteloua gracilis, Lespedeza capitata, Onagra biennis, Solidago missouriensis*, and *Sporobolus cryptandrus* failed to germinate. By June 21, most of the plants were badly wilted and *Liatris scariosa* and *Pinus ponderosa* had succumbed. *Robinia pseudacacia* died in July, *Agropyrum glaucum* and *Petalostemon candidus* by August, while *Amorpha canescens* and *Ratibida columnaris* were found dead on August 31. Only 50 per cent survived. These included slender, delicate specimens of *Andropogon nutans, A. furcatus, Bouteloua hirsuta, B. racemosa, Elymus canadensis, Kuhnia glutinosa*, and *Liatris punctata*. A similar lot of seeds was sown on the surface at Colorado Springs on May 5, but these, like those planted in the trench and denuded quadrats, showed no germination when examined on May 25 and again on July 4, owing to unfavorable holard.

As regards the 1921 surface sowings, it may be recalled that none survived, owing to the dense shade. At Nebraska City, *Bouteloua gracilis* and *B. hirsuta* alone were represented by delicate seedlings at the end of the first

season. However, they held out during the summer of 1922, although very much attenuated. During 1922 they were still very slender and delicate, but they survived this third season of growth, although densely shaded, indicating an unexpectedly high tolerance of shade for the short-grasses.

Trench Sowing.

Seeds of 20 species were planted in a trench on the low prairie on April 20. *Amorpha canescens, Aster multiflorus, Onagra biennis, Ratibida columnaris, Sporobolus asper,* and *Solidago missouriensis* did not germinate. Nearly all of the others grew in considerable abundance, except *Bouteloua hirsuta* and *Liatris punctata,* which were represented by a few plants each, all dying before the end of June. The others did quite well during the rainy month of July, *Liatris scariosa, Lespedeza capitata,* and *Muhlenbergia pungens* disappearing by August. Nine species (64 per cent of those that germinated) became permanently established, and although slender were in fairly good condition at the end of the summer.

A similar lot of seeds, representing 21 species, was planted in a trench in subclimax prairie on April 22. Eight species, including 3 which grew at Lincoln, failed of germination. *Agropyrum glaucum, Muhlenbergia pungens, Petalostemon candidus,* and *Pinus ponderosa* died before June 20, the last having been dug up by rodents. *Andropogon nutans, A. furcatus, Liatris scariosa* and *punctata* died before the middle of July, and *Elymus canadensis* in August. This left a few weak plants each of *Bouteloua racemosa, Kuhnia glutinosa,* and *Robinia pseudacacia,* but a good sod of *Andropogon nutans* 7 to 9 inches high.

Of the 1921 trench plantings on the low prairie, remnants of *Aristida purpurea* alone survived the first season, and these were accidentally destroyed the next spring in transplanting. At Nebraska City, *Andropogon nutans* alone was alive the following spring. In 1922 it reached a height of 13 inches, and did quite as well the next season, but it failed to blossom. On the gravel-knoll, *Andropogon nutans* alone survived, but although it grew well early the next spring, it died the following June.

Denuded Quadrats.

On April 20, 27 species were sown in denuded quadrats on the low prairie. Five did not germinate. These belonged to different species from those failing of germination in the trench, and included *Brauneria pallida, Corylus americana, Fraxinus lanceolata, Gleditsia triacanthus,* and *Ratibida columnaris.* During the June drought, *Agropyrum, Aristida, Aster, Lespedeza, Liatris punctata,* and *Solidago* succumbed; *Elymus, Muhlenbergia,* and *Ulmus* also died before August 1. This gave a mortality of 40 per cent, though most of the survivors were in good condition at the end of the summer.

Among 32 species planted at Nebraska City, 10 did not germinate. *Muhlenbergia* and *Petalostemon* died before June and the following as a result of the June drought: *Acer saccharinum, Aristida, Liatris scariosa* and *punctata, Ratibida,* and *Ulmus.* Later, *Agropyrum* and *Lespedeza* were lost, giving a total mortality of 46 per cent. Among the survivors were 4 species of trees (two of which, *Acer negundo* and *Gleditsia triacanthus,* were in fine condition), 2 forbs, and 6 grasses. In general, they were in good condition. By the

end of August the average height-level of the grassy vegetation was 16 inches, shade being dense over most of the quadrats. However, very little invasion had occurred.

As to the denuded quadrats planted in 1921, 10 of the 12 species that grew on the low prairie survived the first summer. *Acer negundo, A. saccharinum*, and *Lespedeza capitata* failed to grow the following spring, and *Elymus* died in June, as did also *Bouteloua gracilis*, perhaps as a result of the surface soil washing away from the roots. All of the others except *Corylus americana* made a good growth, the latter being badly eaten by grasshoppers. All were densely shaded and none flowered. *Corylus* did not survive the dry fall and winter following, while *Aristida* died during the summer of 1923, evidently being unable to longer endure the dense shade. At the end of the summer *Sporobolus* was represented by remnants only. *Symphoricarpus* made only a fair growth, while *Andropogon nutans* alone developed normally, reached a height of 25 to 30 inches and merged into the native sod.

At Nebraska City only 8 of the 15 species that grew survived the first summer. *Gleditsia* and *Robinia* failed to appear in the spring of 1922 and *Calamovilfa* died early in June. All of the other species made a good growth, *Andropogon* merging into the native sod. None of the quadrats were much invaded. No flower-stalks were produced by any of the plants. In 1923 the 6 remaining species all did quite well, several of them seeding rather abundantly.

On the gravel-knoll, 40 per cent of the species that grew survived the first season. During 1922 some of the *Lespedeza* seeds, sown the preceding spring, germinated, but these and the few feeble shoots from *Symphoricarpus* rhizomes were all dead by midsummer. *Aristida* and *Elymus* both seeded, but, like *Andropogon*, suffered severely from the August drought. During the following dry fall and winter *Elymus* died, but in 1923 both *Aristida* and *Andropogon* made a good growth and seeded.

Seedling Transplants.

Seedlings were transplanted both on the low prairie and at Nebraska City, 22 pots containing 18 species being used in growing the plants for each station. The transplanting was done at Lincoln on May 17. One lot of *Agropyrum* died in June and another in July, together with *Elymus*, *Koeleria*, *Liatris*, and *Stipa spartea; Ratibida*, *Kuhnia*, *Argemone*, *Onagra*, and *Psoralea* succumbed in August, making a total loss of 55 per cent. Most of the survivors came through the season in good condition, owing to the adequate water-content even during the August drought.

At Nebraska City, *Agropyrum*, *Koeleria*, *Lespedeza*, *Solidago*, and *Stipa viridula* died before the end of June. Three others failed in July, viz, *Aristida*, *Glycyrrhiza*, and *Liatris*, and August added *Psoralea* to the list, making a total of 41 per cent. Most of the survivors grew well, *Bouteloua hirsuta* putting forth flower-stalks.

To complete the history of the 1921 seedling transplants, only 14 per cent survived on the gravel-knoll, constituted by *Bouteloua hirsuta* and *Andropogon nutans*. During 1922 these made only a poor vegetative growth, frequently wilting, and did not put forth flower-stalks. By August 1923 they had reached a height of 8 inches, neither coming into blossom.

On the low prairie a single species died the first season, but by the next spring *Aristida purpurea* and *Liatris scariosa* were dead and *Bouteloua racemosa* was represented by a single plant which died in June. The rest made a fair to excellent growth, except *Stipa comata.* The shade was dense and *Elymus canadensis* alone grew above the general level and headed at 35 inches. No others blossomed.

During the summer of 1923 the following species were so deeply shaded that they died: *Bouteloua hirsuta, B. gracilis, Liatris punctata, Stipa viridula,* and *S. comata. Elymus* headed at about 3 feet and *Stipa spartea* seeded at 2 feet, but neither *Andropogon nutans,* which did poorly, nor *A. furcatus* showed signs of flower-stalks by the last of August.

TABLE 35.—*Growth of species in cultivated soil.*

Species.	Degree of development during first season.
Agropyrum glaucum	Good growth of foliage; maximum 2 feet; no flower-stalks.
Andropogon furcatus	Fine bunehes; foliage 18 in.; a few flower-stalks 36 to 38 in.
halli	Foliage 16 in.; flower-stalks 30 in. (cf. plate 12 c).
nutans	Exeellent growth; 20 in., seeding abundantly at 3 to 4.5 feet.
Aristida purpurea	Large bunehes; foliage 11 in.; flower-stalks 18 in.
Bouteloua graeilis	Dense growth; leaves 14 in.; flowering profusely at 15 to 22 in.
hirsuta	Leaves 10 in.; flower-stalks appearing Aug. 8; later 12 in. tall; abundant.
raeemosa	Good growth; ave. height 13 in.; flower-stalks 3 to 3.5 feet.
Calamovilfa longifolia	Foliage 16 in.; no flower-stalks.
Desmodium canescens	Flower-stalk appearing July 10; fruited abundantly at 5 feet (cf. plate 14 B).
Elymus eanadensis	Foliage 2 feet; flower-stalks 4 to 5 feet; very large heads.
Kuhnia glutinosa	34 in. tall; fruiting abundantly.
Lespedeza capitata	Fine plants, 20 to 24 in.; seeded abundantly.
Liatris seariosa	3 to 6 in.; many leaves per plant.
Muhlenbergia pungens	9 in.; flowered and seeded profusely at 14 to 16 in.
Onagra biennis	One rosette 28 in. in diameter; many smaller ones; many had flower-stalks 5 to 5.5 feet tall; blossomed.
Panicum virgatum	Average height foliage 29 in.; seeded abundantly at 3 to 3.5 feet.
Petalostemon candidus	Excellent growth; very mueh bunched stems, 8 to 12 in. tall.
Pinus ponderosa	Five plants, 4 to 5 in. tall.
Robinia pseudacaeia	Stems nearly an ineh in diameter and 7.5 feet tall.
Sporobolus asper	9 in. tall; flower-stalks 14 to 16 in.; seeded profusely.
Stipa viridula	Foliage about 16 in. tall; maximum 26 in.; no flower-stalks.

At Nebraska City, 6 of the 13 species of seedlings died the first summer; Regardless of this heavy mortality, all the species survived the summer of 1922, notwithstanding the drought. However, all suffered more or less severely in late summer, *Stipa comata* being represented by remnants only at the end of the season. *Bouteloua hirsuta* and *B. gracilis* alone blossomed. The seedling area, although quite shaded by the adjacent vegetation, was not much invaded.

In 1923, *Stipa comata* became badly invaded and died. All the others made a good growth.

EFFECT OF COMPETITION.

In order to determine the effects of competition upon the development of the species investigated, many of them were grown in a cultivated area at Lincoln, kept free from weeds by hoeing, and watered from time to time (table 35).

The fine growth made in a single season by these species is in striking contrast to that under even the most favorable method of planting in the grassland and emphasizes the striking effect that competition plays in limiting plant development under natural conditions. Plants growing for a second year under cultivation made no less remarkable growth. *Bouteloua gracilis* had an average height of foliage of 19 inches, spread 15 inches on either side of the trench, and some of the flower-stalks were 32 inches tall. *Agropyrum glaucum* was 29 inches tall, with a maximum height of 44 inches, and had spread 6 feet by rhizome propagation. A single plant of *Onagra biennis* had 3 stems which reached a height of 7 feet and 12 others of lesser height, all from the same rosette (plate 14).

Summary.

A summary of planting experiments is given in table 36, where for purposes of comparison the high prairie is included. The germination of surface-sown seed was not greatly different at the three stations (70 to 84 per cent),

Table 36.—*Summary of planting experiments, 1922.*

Method of seeding.	Per cent of germination.			Per cent of establishment of germinated species.		
	High prairie.	Low prairie.	Nebraska City.	High prairie.	Low prairie.	Nebraska City.
Surface sowing......	82	84	70	50	25	50
Trench............	70	60	62	63	64	33
Denuded quadrat....	71	81	69	72	60	54
Average........	74	75	67	62	50	46
Seedlings...........	..	..	..	70	45	59

that on the low prairie being highest. Germination in denuded quadrats was also about 10 per cent greater on the low prairie than elsewhere, Nebraska City ranking third. Averaging the results of the three methods, 75 per cent germination occurred on low prairie, 1 per cent less on high prairie, and 8 per cent less at Nebraska City.

Because of the effect of the luxuriant vegetation of the low prairie in reducing the light intensity, a factor which quite outweighed the higher water-content, establishment averaged lower here (50 per cent) than on high prairie (62 per cent) and was least at Nebraska City (46 per cent). The last fact can be directly correlated with drought, especially when it is recalled that the surface sowing at Lincoln was watered. Similar conditions hold for the seedling transplants. A survey of the data shows clearly that while surface sowing gave the greatest per cent of germination, the best establishment occurred in the denuded quadrats. Compared with the western stations, both the per cent of germination and establishment averaged higher.

Sod Transplants.

Twenty-eight blocks of soil, comprising 25 species, were transplanted from the several habitats about Lincoln into the low prairie on March 22. These included 11 subdominant forbs, as well as all of the most important grasses.

Agropyrum glaucum grew poorly, not attaining a height greater than 11 inches and failing to flower. *Astragalus crassicarpus, Brauneria pallida,* and *Psoralea tenuiflora floribunda,* all provided with strong tap-roots necessarily cut off in transplanting, languished and died within a few weeks. All of the rest, however, came through the season in good condition, 75 per cent of the dicotyls and 50 per cent of the grasses flowering.

A lot of sods, including 11 species from Arizona, were transplanted into low prairie early in May. The blocks were very small, being only 3 or 4 inches in diameter, and it seems probable some were dead when transplanted. In spite of sufficient watering the following did not grow: *Aristida divaricata, A. purpurea, Bouteloua eriopoda, B. hirsuta, B. racemosa, Hilaria mutica, H. cenchroides, Sporobolus wrighti,* and *Valota saccharata. Andropogon saccharoides* put forth 3 green shoots, which reached a height of 11 inches before they died in August. *Bouteloua bromoides* and *Hilaria cenchroides* formed good clumps 5 to 8 inches high, the former bearing flower-stalks 8 to 13 inches tall. However, both were winterkilled, notwithstanding the fact that they were well covered with a mulch of dead grasses. The following species from Arizona were also transplanted into high prairie at the same time: *Aristida divaricata, A. purpurea, Bouteloua eriopoda, B. bromoides, B. hirsuta* (all of which died promptly), and *Hilaria cenchroides.* The last made a sparse growth, reaching a height of 8 to 10 inches in August, but died under a mulch during the following winter.

Sod of 14 species of grasses from both high and low prairie were transplanted into the salt-flat near the low-prairie station late in March. *Andropogon nutans, A. furcatus, Panicum virgatum,* and *Sporobolus asper* did very poorly, making only a sparse growth, yellowing and wilting from time to time. By June 22 not only this lot of transplants, but also those of previous years were in very poor condition. Large cracks occurred around most of the blocks of sods and some were almost dried out. Shading played rather an unimportant rôle, since the height of the *Distichlis* was only 18 inches. *Sporobolus* died late in July, and the others made a fair to poor growth only. Nearly all were more or less dwarfed and of a light-green color, and the inflorescences were often reduced. In fact, only 5 species (36 per cent) seeded; these were *Bulbilis dactyloides, Bouteloua gracilis, Elymus canadensis, Koeleria cristata,* and *Stipa spartea.*

On April 5, 14 species were transplanted into the former swamp area. Silting up since the building of a dam, as well as the enormous losses by transpiration from the rank growth of vegetation, had decreased the water-content. On June 7 the holard at any depth did not exceed 22 per cent, which was the amount in the surface 6 inches; by June 22 it had fallen to 15 per cent or less in the surface 2 feet. It seems evident that there was no excess moisture or deficient aeration and that light was the controlling factor. By May 6, *Spartina* was 8 to 10 inches tall, and it had reached a level of 32 inches by the middle of June. In August a rank growth of *Spartina, Phalaris,* etc., 4 feet tall, covered the area; light readings at this time gave values of 1.5 to 11 per cent. *Andropogon furcatus, A. scoparius,* and *Panicum virgatum,* although starting out well, were badly invaded by the swamp dominants and died by the middle of July, as did *Andropogon nutans* later in the summer. All suffered severely from shading, as was evidenced by the attenuated leaves

and slender flower-stalks of the 5 species that blossomed, viz, *Agropyrum*, *Bulbilis*, *Elymus*, *Koeleria*, and *Stipa*. The species of the following genera came through the season in fair to good condition: *Agropyrum*, *Bulbilis*, *Elymus*, *Koeleria*, *Spartina*, and *Stipa*. *Bouteloua gracilis*, *B. hirsuta*, *B. racemosa*, and *Sporobolus* were in poor condition by autumn.

Duplicate blocks of sods of the following species were shipped from Lincoln and transplanted at Colorado Springs on March 28: *Andropogon scoparius*, *A. furcatus*, *A. nutans*, *Elymus canadensis*, *Sporobolus asper*, *Stipa spartea*, *Koeleria cristata*, *Bouteloua racemosa*, *B. gracilis*, *B. hirsuta*, *Bulbilis dactyloides*, *Panicum virgatum*, *Spartina cynosuroides*, and *Agropyrum glaucum*. All were growing vigorously on May 21, but were considerably eaten by grasshoppers and doing rather poorly by July 4. A final check on August 24 showed that *Bulbilis dactyloides* alone had blossomed, and no flower-stalks were appearing on any of the other species. *Sporobolus asper* had died, and *Elymus*, *Andropogon furcatus*, and *B. racemosa* were eaten back to mere remnants. Triplicate sods of *Stipa viridula*, *Muhlenbergia gracilis*, *M. gracillima*, and *Sporobolus cryptandrus* were shipped from Colorado Springs and transplanted in the cultivated plats at Lincoln on June 22. The sods were very small and the plants died in spite of ample watering.

Large duplicate blocks of sods were shipped from Lincoln to Berkeley, California, which has an average rainfall of 24 inches, occurring chiefly in the winter months, and a long dry season in summer and autumn. These were transplanted on December 4 (1921), the species employed being *Andropogon scoparius*, *A. furcatus*, *A. nutans*, *Elymus canadensis*, *Stipa spartea*, *Koeleria cristata*, *Bouteloua racemosa*, and *Bulbilis dactyloides*. The sods were set on a dry west exposure in a heavy clay soil covered chiefly with introduced weeds, such as *Avena fatua*, *Brassica campestris*, and *Raphanus sativus*. Owing to an abundance of rain, conditions at the time of transplanting were very favorable for growth. The original vegetation was bunch-grass prairie composed mostly of *Stipa setigera*, as indicated by the relicts of this. Some attention was given the sods in 1921 and 1922, at first a little water, and then occasional removal of the competing weeds. Most of the grasses did not survive the first dry season, but *Elymus canadensis* made a good growth. *Bulbilis dactyloides* persisted for a time, and *Poa pratensis* spread at first, but succumbed when water was withheld. Even *Elymus* was unable to survive the exceptionally dry spring and summer of 1923, and the plot was finally destroyed by the great fire of September 1923. The failure of the grasses to establish themselves was due chiefly to inability to pass the long dry seasons and to competition as a contributing factor, but the experiment was on too small a scale to justify the conclusion that none of the species could be established.

A number of grasses from the Santa Rita Reserve near Tucson, Arizona, were planted under the same conditions at Berkeley. The sods were set April 3, 1921, and comprised *Andropogon saccharoides*, *A. contortus*, *Aristida divaricata*, *A. purpurea*, *Bouteloua bromoides*, *B. hirsuta*, *B. racemosa*, *B. rothrocki*, *B. eriopoda*, *Hilaria cenchroides*, *H. mutica*, and *Sporobolus wrighti*. All of these made some growth in 1921, but by the autumn of 1923 all had succumbed except the following: *Andropogon saccharoides* grew vigorously in 1922, reaching a height of 4 feet, flowered, and set seed abundantly; in 1923

the 3 plants were growing and flowering, with a slight tendency to increase but not spreading over the ground, and no seedlings were noticed; *Hilaria mutica* made an attempt to establish itself and 1 of the 3 tufts was still living; *Aristida divaricata* was in the same condition as the *Hilaria; Bouteloua bromoides* made a good start and flowered in 1922, but disappeared during the long dry summer of 1923; *Sporobolus wrighti* grew each season, and although it did not spread, was holding its own, even against the weedy grasses with which it had to compete during the spring and early summer. It is instructive to note that the grasses from the desert plains grew better than those from the true prairies, a fact readily explained by the greater similarity in climate and climax between Arizona and California.

5. EXPERIMENTS DURING 1923.

DEVELOPMENT OF SEEDLINGS AND TRANSPLANTS.

It remains only to trace the history of the 1922 plantings through the period from September 1922 to the end of the summer of 1923.

Physical Factors.

Water Relations.

The fall and winter of 1922 constituted a period of great drought. Some idea of its intensity may be gained by an examination of the rainfall data in table 37.

Table 37.—*Precipitation from August 1922 to August 1923.*

	Burlington.		Phillipsburg.		Lincoln.	
	Total.	Departure from mean.	Total.	Departure from mean.	Total.	Departure from mean.
August.......	3.04	+0.50	1.13	−1.77	0.69	−3.02
September....	0.16	−1.23	0.94	−1.58	2.12	−0.52
October......	0.18	−0.75	0.44	−1.04	1.42	−0.40
November....	1.44	+1.01	0.40	−0.28	2.62	+1.77
December....	0.00	−0.63	0.00	−0.82	0.06	−0.61
January......	0.00	−0.26	0.00	−0.44	0.14	−0.48
February.....	0.10	−0.36	0.16	−0.65	0.66	−0.04
March.......	0.36	−0.47	1.31	+0.52	1.77	+0.44
April.........	1.66	−0.40	3.40	+1.07	2.21	−0.56
May.........	No report.	....	7.86	+4.85	3.31	−0.94
June.........	3.03	+0.26	4.94	+1.03	5.25	+0.93
July.........	4.33	+1.56	2.34	−0.62	1.88	−1.95
August.......	4.89	+2.30	1.85	−0.95	5.50	+1.79

Although Burlington had an excess of 0.5 inch in August, drought at the other stations began during this month. Precipitation was below normal at Burlington (except during November) until May, and the same was true at Lincoln until June, except a slight excess in March, while at Phillipsburg it was exceedingly low until March. However, it should be noted that the spring and summer rainfall was high at the western stations, although below normal at Lincoln during April and May and again in July. The season was one which promoted excellent growth. Not only was the rainfall generally above normal, but the rains were also well distributed, drought periods westward being fewer and shorter than usual. This was indicated by the excellent growth of *Bouteloua gracilis*, which reached a height of 12 to 18 inches at Burlington and also by the fact that the short-grasses remained green or dried only slightly throughout the entire summer. Conditions were slightly less favorable in August at Lincoln and at Phillipsburg, where the three grama grasses ripened seed. On the whole, vegetation grew well at Lincoln, the grasses on the gravel-knoll remaining green all summer. An examination of the chresard taken at intervals in the various stations (table 38) is illuminating in this connection.

The very low water-content on the high prairie in October is remarkable; on the gravel-knoll practically no water was available to 4 feet, and it was not

high even on low prairie. By March 1 a good water-content was found at both prairie stations and available moisture to the amount of 3 to 7 per cent was present throughout the season. The adequate holard in the surface layers at Burlington during July and August was very unusual. At Phillipsburg, as already indicated, it was drier in August. Because of the drought of autumn and late winter, many species under all methods of planting and transplanting were killed (table 39).

Table 38.—*Holard in excess of hygroscopic coefficient at the several stations, 1923 (unless otherwise indicated).*

Station.	Date.	Depth in feet.				
		0 to 0.5	0.5 to 1	1 to 2	2 to 3	3 to 4
Lincoln:						
High prairie	Oct. 27, 1922	1.8	3.7	3.0	2.8	3.8
Do	Mar. 1	18.1	18.3	12.1	10.7	7.3
Do	June 2	10.4	16.6	16.7	11.5	8.2
Do	July 23	3.0	4.3	5.4	7.1	7.5
Do	Aug. 3	4.2	5.4	5.0	6.4	8.2
Do	Aug. 23	12.5	16.4	6.3	7.1	8.7
Gravel-knoll	Oct. 27	−1.5	1.0	−0.8	1.5	3.1
Do	June 2	−0.6	1.0	3.1	9.8	7.6
Burlington	July 6	0.4	−0.7	0.2	0.8	−0.6
Do	July 19	10.0	0.0	−0.3	−0.2	−0.2
Do	Aug. 21	5.8	4.5	−0.2	−0.7	−0.6
Phillipsburg	June 20	11.3	13.3	11.1	12.6	11.9
Do	Aug. 22	−0.6	1.5	0.7	1.6	5.6
Nebraska	May 27	20.9	20.0	17.7	13.9	12.7
Do	Aug. 28	22.7	20.0	9.5	6.7	7.7
Lincoln:						
Low prairie	Oct. 27	3.5	5.8	6.2	8.3	13.2
Do	Mar. 1	22.4	21.1	11.8	11.3	16.4
Do	Aug. 23	11.4	18.4	13.4	8.0	14.0

Survival Results.

An examination of the data in table 39 reveals a number of interesting facts, the two most important of which are as follows: Losses at the three major climatic stations were greatest at Burlington, intermediate at Phillipsburg, and least at Lincoln. The losses at all stations averaged highest for the plants of a single year's establishment, next for those 2 years old, and least for those established for 3 seasons. With a single exception, survival was greatest at all 3 stations under the method of denuded quadrats, this even exceeding that of transplanting blocks of sods. Surface sowing gave the lowest survival.

Survival on the low prairie and at Nebraska City was very similar, following the sequence stated above as regards length of establishment. Except for 1920 (when all averages were very high) it exceeded that on the high prairie at Lincoln, and naturally that at the western stations. Survival on the gravel-knoll of species grown for at least two summers was remarkably high, though few species were concerned, with the exception of sod transplants.

Surface Sowing.

Nine of the 18 species that germinated on the surface of the high prairie at Lincoln died by the end of August. Because of the exceedingly dry autumn and winter, 6 species were winterkilled, leaving only 33 per cent of the survivors of the first summer. *Petalostemon candidus* had only two very delicate plants 3 to 5 inches tall by autumn, but *Andropogon furcatus* and *A. nutans* had both made a good growth, reaching a height of 10 or 12 inches.

Table 39.—*Comparative survival at the different stations during fall and winter of 1922-23.*

Method of planting.	Lincoln, high prairie.	Phillipsburg.	Burlington.
1920.			
Surface sowing....	...	...	100
Trench planting...	100	100	...
Denuded quadrats.	100	100	100
Seedlings.........	...	...	60
Sod transplants....	94	...	52
Average......	98	100	84
1921.			
Surface sowing....	...	50	...
Trench planting...	100	50	...
Denuded quadrats.	100	100	50
Seedlings.........	60	68	...
Sod transplants....	94	...	63
Average.	89	72	57
1922.			
Surface sowing....	33	38	...
Trench planting...	40	50	0
Denuded quadrats.	78	72	22
Seedlings.........	79	50	20
Sod transplants....	86	...	17
Average......	63	53	15

Method of planting.	Lincoln, low prairie.	Nebraska City.	Gravel-knoll.
1920.			
Surface sowing....	...	...	...
Trench planting...	100	100	...
Denuded quadrats.	100	88	...
Seedlings.........	...	...	...
Sod transplants....	79	...	94
Average......	93	94	94
1921.			
Surface sowing....	...	100	...
Trench planting...	...	100	...
Denuded quadrats.	80	100	67
Seedlings.........	100	88	100
Sod transplants....	100	...	100
Average......	93	97	89
1922.			
Surface sowing....	17	57	...
Trench planting...	78	50	...
Denuded quadrats.	85	75	...
Seedlings.........	70	85	...
Sod transplants....	80	...	...
Average......	66	67	...

In the mixed prairie at Phillipsburg, 8 species, 4 of which were in very poor condition, survived the first season. *Andropogon nutans, A. furcatus, Desmodium canescens, Elymus canadensis,* and *Kuhnia glutinosa* were winterkilled, leaving only the 3 species of *Bouteloua.* None of these had seeded by the following August, but all were in fair condition, having reached heights of 4 to 8 inches. None of the surface-sown plants survived the summer at Burlington.

Trench Sowing.

Of the species sown in a trench on the high prairie, 63 per cent lived through the first season, most of them being badly dried out late in August; 5 of the 10 did not grow the next spring, viz, *Andropogon furcatus, Aristida purpurea, Elymus canadensis, Liatris scariosa,* and *Robinia pseudacacia. Andropogon nutans* and *Pinus ponderosa* had succumbed by August of 1923, leaving only several fine clumps of *Bouteloua racemosa* and 4 good plants of *Desmodium canescens,* each about 8 inches tall. Plants in the trench at Phillipsburg were represented in the fall of 1922 by *Andropogon nutans* and *Bouteloua racemosa* only. The last was winterkilled, while *Andropogon* was represented by very much attenuated plants 8 inches tall, the shade being very dense again during 1923. At Burlington, *Andropogon nutans* alone survived the summer, but it died the following fall or winter.

Denuded Quadrats.

Of the 25 species that grew in the denuded quadrats on the high prairie, 18 survived the first summer. Of these, *Aristida purpurea*, *Desmodium canescens*, *Onagra biennis*, and *Pinus ponderosa* succumbed by spring. *Andropogon scoparius* and *Muhlenbergia pungens*, which were represented by a single clump each, died before September 1923. *Acer saccharinum* was killed back to within 6 inches of the soil, 16 of the trees dying; however, like all the other species, they made a good growth during the summer. Exceptions to this were *Bouteloua gracilis*, *Sporobolus asper*, and *Robinia pseudacacia*, which did poorly. None of the species blossomed. The quadrats were only slightly invaded. It is interesting that not only grasses and forbs, but also certain trees, survived the second summer.

At Phillipsburg only half of the species that germinated in the denuded quadrats lived to the end of the first summer. *Andropogon furcatus*, *Gleditsia triacanthus*, and *Acer saccharinum* were winterkilled. Although all quadrats were densely shaded by a rank growth of *Bouteloua gracilis* 18 to 24 inches high, the 8 remaining species all did well. *Aristida purpurea* failed to blossom, as did also *Andropogon nutans* and *Panicum virgatum*. The rest, viz, *Bouteloua racemosa*, *B. gracilis*, *Sporobolus asper*, and *Petalostemon candidus*, seeded, the last at a height of 2 to 2.5 feet. At Burlington, 64 per cent survived in the denuded quadrats. Because of the very dry fall and winter that ensued, only 2 of the 9 species showed renewed growth the following spring. *Bouteloua gracilis* formed excellent clumps and flowered profusely in 1923. *Elymus canadensis*, the other survivor, was represented by a single stalk which headed at 16 inches.

Seedling Transplants.

Of the seedlings transplanted into high prairie in the spring of 1922, only 70 per cent survived, notwithstanding that they had been regularly watered throughout the summer. Of the 14 survivors, *Elymus*, *Petalostemon*, and *Argemone* were winterkilled. *Onagra* died during the following summer, but all of the others made a good growth, though none came into blossom. Of the 19 species of seedlings grown in the mixed prairie, 15 survived, but 8 of these were winterkilled. Although the rest made a good growth during the following summer, *Bouteloua gracilis* and *Ratibida columnaris* alone came into bloom. At Burlington only 5 of the 19 species transplanted survived. All but one were winterkilled, viz, *Sporobolus*, *Bouteloua racemosa*, *B. hirsuta*, and *Stipa viridula*, *Bouteloua gracilis* alone surviving. This did fairly well in 1923, but produced no flower-stalks.

EXPERIMENTS AT EDAPHIC STATIONS.

Survival Results.

Surface Sowing.

On the low prairie, owing to dense shading, only 25 per cent of the 1922 surface-sown plants survived the first summer. *Aristida*, *Andropogon furcatus*, *A. nutans*, *Bouteloua gracilis*, *B. racemosa*, and *Petalostemon candidus* did not grow the following spring. *Andropogon nutans* alone survived, and at the end of the following summer the slender plants were a foot high.

At Nebraska City, 50 per cent of the species survived. *Bouteloua hirsuta*, *Elymus canadensis*, and *Kuhnia glutinosa* were winterkilled and *Bouteloua racemosa* died by the end of the next summer. *Andropogon nutans*, *A. furcatus*, and *Liatris punctata* alone survived. In all cases the plants were very much attenuated and it seemed doubtful if they would ecize.

Trench Sowing.

As regards the trench plantings in the low prairie, 9 species, i. e., 64 per cent of those that germinated, grew throughout the first summer. *Aristida* and *Kuhnia* were winterkilled and *Andropogon furcatus* died the following summer. All the remaining species were very slender, *Elymus* and *Petalostemon* being represented in August by remnants only. *Andropogon nutans*, *Bouteloua gracilis*, *B. racemosa*, and *Desmodium canescens*, which made up the remainder, reached heights of 6 to 8 inches, but none seeded. Of the 21 species planted in the Nebraska City trench, only 4 survived, and of these *Kuhnia glutinosa* and *Robinia pseudacacia* were winterkilled. *Andropogon nutans* and *Bouteloua racemosa* were each represented by clumps of rather slender plants at the end of the following summer.

Denuded Quadrats.

On the low prairie at Lincoln, 60 per cent of the 1922 plantings in quadrats survived, *Amorpha canescens* and *Onagra biennis* alone succumbing during the following winter. At the end of August 1923, the following were in very poor condition, being represented by remnants only: *Bouteloua gracilis*, *B. hirsuta*, *Sporobolus asper*, and *Acer saccharinum*. The 7 remaining species, although somewhat slender, had made fair to good growth, but none seeded. At Nebraska City, 12 species survived the first summer. A fourth of these, including *Andropogon furcatus*, *Desmodium*, and *Kuhnia* were winterkilled, and *Robinia pseudacacia* died later. All of the remaining species made good growth, *Andropogon nutans* forming a dense sod.

Seedling Transplants.

Of the species transplanted as seedlings into the low prairie, 45 per cent survived the first summer, but among these *Stipa viridula*, *Petalostemon candidus*, and *Kuhnia* were winterkilled. All the rest, including the 3 gramas, *Sporobolus*, *Desmodium*, and *Andropogon nutans*, prospered until the end of the growing-season.

At the Nebraska City station, 13 species (59 per cent) lived to the end of the first summer. *Petalostemon* and *Ratibida* were winterkilled. All of the others made a good growth because of the favorable season, with the exception of *Onagra*, which died in midsummer.

Summary of Survival.

The fate of the 1922 plantings by the end of 1923 is shown in table 40.

Under all methods of planting or transplanting, the survival at the end of the second season of growth was greatest at Lincoln, intermediate at Phillipsburg, and least at Burlington. Of the several methods of planting, survival in the trench was lowest and surface sowing next, while the denuded quadrats were only slightly more successful than the seedling transplants. The average survival on the low prairie at Lincoln was greater than at Nebraska City, but the latter was nearly equal to that on high prairie at Lincoln. On low prairie and at Nebraska City the success of the several methods of seeding was in the same order as at the other stations, except that trench planting

outranked surface sowing. The average survival of the seedling transplants at these stations was less than on high prairie (where they were watered the first season), but exceeded that in mixed prairie.

An examination of the species which gave the greatest percentage of survival is of interest. As to surface sowing, *Petalostemon, Andropogon nutans*, and *A. furcatus* alone survived at Lincoln, and the three boutelouas at Phillipsburg, so far as the three major stations are concerned. However, *Andropogon nutans* survived in the two stations at Lincoln as well as at Nebraska City, and *A. furcatus* on high prairie and at Nebraska City. *Liatris punctata* was the only other survivor and was found at Nebraska City alone.

TABLE 40.—*Summary of survival of 1922 plantings in August 1923.*

Method of seeding.	Lincoln.	Phillipsburg.	Burlington.	Lincoln (low prairie).	Nebraska City.
Surface sowing	17	16	0	6	21
Trench	13	13	0	43	15
Denuded quadrats	48	36	14	50	36
Average	26	22	5	33	24
Seedlings	50	37	5	39	45

In the trench, *Bouteloua racemosa* and *Desmodium* were the sole survivors at Lincoln, and *Andropogon nutans* at Phillipsburg, while, as before, none were found at Burlington. But *Bouteloua racemosa* also survived at Nebraska City and on the low prairie and *Andropogon nutans* at both of these stations also. *Desmodium* persisted on low prairie as well as on high prairie. The only other survivors occurred on the low prairie alone, viz, *Elymus, Petalostemon*, and *Bouteloua gracilis*.

With respect to denuded quadrats, *Bouteloua gracilis* persisted at all five stations, *B. racemosa* and *Andropogon nutans* at all but Burlington, *Petalostemon, Panicum*, and *Sporobolus* at three, and *Andropogon furcatus, Kuhnia, Liatris scariosa, Gleditsia, Acer saccharinum*, and *Elymus* at two, while the following were found at only one station each: *Robinia, Bouteloua hirsuta, Desmodium* (at Lincoln), *Pinus*, and *Acer negundo* (at Nebraska City).

Among the seedlings, *Bouteloua gracilis* occurred at all the stations, and *B. hirsuta* and *Sporobolus* at all but Burlington. *Liatris scariosa, Andropogon nutans, Bouteloua racemosa, Stipa spartea*, and *Desmodium* were found at three stations, while *Ratibida columnaris* occurred at two. The following were represented at one station only: *Liatris punctata, Koeleria* (at Lincoln), *Petalostemon* (at Phillipsburg), *Kuhnia*, and *Elymus* (at Nebraska City).

Arranging the species in order of their survival under all methods of planting at the several stations gives *Andropogon nutans* 14, *Bouteloua gracilis* 12, *B. racemosa* 11, *Sporobolus* and *Desmodium* each 7, *Petalostemon* and *Bouteloua hirsuta* each 6, *Andropogon furcatus* and *Liatris scariosa* each 5, *Elymus canadensis* 4, *Panicum virgatum, Kuhnia glutinosa*, and *Stipa spartea* each 3, *Liatris punctata, Gleditsia triacanthus, Acer saccharinum*, and *Ratibida columnaris* each 2, while the following occurred only once: *Robinia pseudacacia, Pinus ponderosa, Acer negundo*, and *Koeleria cristata*.

Bouteloua gracilis was the only species which survived under some method of planting at all 5 stations. The following persisted at both Lincoln and Phillipsburg, but not at Burlington: *Petalostemon, Andropogon nutans, Bouteloua racemosa, B. hirsuta, Panicum, Sporobolus, Stipa spartea, Ratibida,* and *Liatris scariosa.*

Sod Transplants.

As to the 1922 sod transplants on the high prairie, the following died during the fall or winter: *Anemone, Grindelia, Helianthus,* and one lot of *Bouteloua gracilis,* while *Astragalus crassicarpus* died before autumn. Aside from the grasses, nearly all of which made an excellent growth, it is interesting to note that several forbs, viz, *Liatris scariosa, Solidago missouriensis,* and *S. rigida,* blossomed profusely.

At Burlington the fall and winter were so extremely dry that 83 per cent were winterkilled, including 9 species. This left a single sod of each of the following: *Agropyrum, Bouteloua gracilis, Panicum virgatum,* and *Andropogon scoparius.* The last died before the end of the summer. *Agropyrum* was represented by only 3 shoots and *Panicum* by 2, neither species blossoming, but *Bouteloua gracilis* made a good growth and put forth flower-stalks abundantly. The contrast between prairie and plains is consequently very sharp and the disaster met by planted or transplanted species in the latter area needs no emphasis. The indications in 1923 were that *Bouteloua gracilis* and possibly *Agropyrum glaucum* were the only species that would survive permanently.

Sods transplanted to the low prairie in 1922 were winterkilled to the extent of 5 species, while *Agropyrum, Bouteloua gracilis,* and *Bouteloua hirsuta* died the following summer. By the end of the season *Koeleria* and *Anemone* were nearly dead, due to the severe competition and dense shade. Although all of the other species were still prospering, the condition of the transplants made in 1920 and 1921 indicated that a year or two would suffice to eliminate the upland species and leave the taller subclimax grasses and forbs in possession of the area.

None of the 1922 sods in the salt-flat were winterkilled, but *Bouteloua hirsuta* died the following summer. In August 1923, *Koeleria* was represented by mere remnants, while several of the other species evidenced by their paler color and dwarfed habit the uncongenial nature of the habitat, notwithstanding the rather wet season. However, all did fairly well, but several failed to bloom.

As to the species transplanted into the former swamp area in 1922, *Sporobolus* and two lots each of *Bouteloua hirsuta* and *B. racemosa* failed to grow the following spring. The slough-grass cast a very dense shade, and by the end of 1923 *Bulbilis, Elymus,* and *Bouteloua gracilis* had died, while *Agropyrum* was represented by mere remnants. This left *Spartina,* which had made a normal growth, *Stipa spartea,* the flowers of which were still in the leaf-sheath in late August, and *Koeleria,* which failed to blossom. In another season it is probable that these two high-prairie species would also have been eliminated.

The sods planted in 1922 at Colorado Springs did poorly because of grazing. By the end of the second summer, *Andropogon furcatus, Panicum virgatum,* and *Bouteloua racemosa* had died, and *Elymus* and *Spartina* were represented by mere remnants. None but *Bulbilis* had blossomed.

PHYTOMETRIC RESULTS.

Transpiration and Growth.

Plan.

In order to obtain further light as to the climatic differences of the major stations in terms of functional response, a special investigation was made of transpiration and growth during the summer of 1923. Plants of *Helianthus annuus*, *Avena sativa*, *Elymus canadensis*, and *Acer negundo* were grown from seed or transplanted as seedlings into sheet-metal containers of appropriate shape and sufficient size to accommodate the root systems throughout the duration of the experiment. After the plants were well established, the leaf area and the weight of plant and container were determined. They were then installed at the several stations, together with a complete battery of instruments, for a period of 14 days, and measurements made of transpiration and growth in terms of increased area. The considerable differences in altitude and hence in seasonal development made simultaneous studies undesirable, and consequently the periods of observation were successive. This was also imperative because of the time and effort involved.

Methods.

The individual plants of sunflower and box-elder were placed in cylindrical galvanized-iron containers 5 to 6 inches in diameter and 9 to 10 inches deep, filled with rich loam soil tamped firmly in place. A layer of one-half inch of coarse gravel in the bottom of the container covered an exit-tube, consisting of an automobile tire valve-stem with the inner end cut off and covered with a fine copper gauze soldered in place. The core of each tube had been removed. The tube was soldered in place with the threads projecting through the wall of the container, so that an exhaust pump could be attached for aerating the soil. The tube also assisted materially in watering the plants, the usual cap preventing loss during the intervals. The soil was well screened, brought to an optimum holard, and weighed at the time of filling the containers. By restoring the containers to their original weight from time to time, the holard was maintained at the desired level. To prevent loss other than by transpiration, the containers were furnished with a sloping metal top provided with a circular opening with the edges reamed upward, and large enough to receive a cork 2.5 inches in diameter. An effective seal was formed by boring a hole large enough for the plant stem, splitting the cork and fitting it into place after padding the sides of the opening with a little cotton. The seal was tested by a check container without a plant, but fitted with a wooden peg to simulate the plant stem. During the period of 14 days this did not lose water in an amount sufficient to be detected by a balance sensitive to 2 grams under a load of 7 kg.

The containers for wild rye and oats were similar to those already described, except for the tops, which were furnished with a slit 5 inches long and 1 inch wide. The edges of the metal cut in making the slit were turned down into the container about a quarter of an inch on each side and a half-inch at the ends of the slit. These furnished supports for narrow strips of shellacked oak, which were held in place by thin wedges of similar material at each end. These were put in place after the containers had been filled and the soil pressed

firmly under the metal tops. They were then coated with shellac, so that no openings remained except between the wooden strips, which narrowed the slit to about 10 mm. The seeds were planted through this opening, which was nearly filled with soil kept moist by frequent watering. After the plants came up, the remainder of the opening was filled with sand level with the top of the wooden strips. The containers were provided with felt tops, cut to fit around the slits, and sunken level with the soil. The efficiency of the sand-mulch in preventing water-loss was found to be high, only 6 grams escaping in a period of 2 weeks. Twelve plants of average size were selected from the several containers and the leaf-area determined. From this, and the number of plants in each container, the initial area of the group of plants in any container was calculated. The final area was determined in a similar manner. This method was used because it was quite impossible to determine the total area of the plants in place, as could be done with the dicotyls.

Owing to cool, wet weather, the plants grew slowly, except during the last week of May. They were kept covered during rains and at night, watered from a burette, and aerated from time to time. To keep the metal containers from heating the soil, they were surrounded by sand and the top covered by a collar of felt about a centimeter thick, held in place by strips of adhesive tape. On June 1 the leaf-area was determined by means of solio prints and the planimeter, corks were inserted, and the containers (with collars removed) brought back to their initial weight after they had been transported to the station in the high prairie at Lincoln. Here they were placed in the soil and thoroughly covered after the collars had been replaced, the exposed plants being sheltered during rains.

After the 14-day period of the experiment, following final weighings,the number of parent plants and number of tillers in each container was ascertained. Eighteen specimens of each group were then selected and their areas determined. From these data the final areas were calculated.

Conditions and Results at Lincoln.

Physical Factors.

The period (May 31 to June 15) was exceptionally cool and wet. Only one entire day was sunny, and the sun shone for over half of the time on two others alone. During a 4-day interval the sun did not appear, while the total sunshine over the whole period was approximately 5.5 days. A total of 4.9 inches of rain fell during 8 days, and rains occurred in the daytime on 6 days, during one of which it was necessary to keep the plants sheltered for the entire day. In fact, they were under cover for a total period of 30 hours of daylight in which rain was falling.

The air-temperature during the first 7 days ranged from 55° to 91° F., while the humidity was never lower than 55 per cent. This was followed by a period of 4 days when the temperature remained at 58° to 65° F. and the humidity above 80 per cent. The remaining time was similar to that of the first 7 days. The average day temperature for the entire period was 70.1° F. and the day humidity 75 per cent. The soil temperature at a depth of 6 inches among the containers varied from 62° to 71° F. The total wind movement at a height of 39 cm. during the period was 1,282 miles, an average of only 3.6 miles per hour. The exceptionally mesophytic conditions are shown by the average

TABLE 41.—*Water-loss and growth at Lincoln.*

HELIANTHUS ANNUUS.

Container.	Initial weight, June 1 (grams).	Water added (grams). June 4.	June 12.	June 14.	Final weight, June 15 (grams).	Total water used (grams).	Initial area (sq.cm.).	Final area. (sq. cm.)	Average area (sq.cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
1	6,748	300	250	100	6,464	934	229.1	960.5	594.8	15.7	319.2
2	7,053	300	250	100	6,700	1,003	266.9	1,135.5	701.2	14.3	325.4
3	7,035	300	250	100	6,690	995	237.9	1,142.4	690.1	14.4	380.2
4	6,793	300	250	100	6,587	856	167.0	1,029.1	598.1	14.3	516.2
5	6,942	300	250	100	6,769	823	156.7	1,075.9	616.3	133	586.6
6	6,966	300	250	100	6,660	956	258.5	1,099.4	678.9	141	325.3
7	6,898	300	250	100	6,646	902	201.0	1,127.9	664.5	135	461.1
8	6,700	300	250	100	6,452	898	202.7	921.1	561.9	159	354.4
9	6,974	300	250	100	6,629	995	177.3	1,124.4	650.8	153	534.2
10	6,800	300	250	100	6,516	934	244.2	928.8	586.5	159	280.3
11	6,980	300	250	100	6,655	975	275.1	1,205.7	740.4	132	338.2
12	6,962	300	250	100	6,672	940	187.5	1,106.1	646.8	145	489.9
Aver....	....	.....	.....	.....	....	....	....	....	....	145	409.2

AVENA SATIVA.

Container.	Initial weight, June 1 (grams).	Water added (grams). June 7.	June 13.	June 15.	Final weight, June 1 (grams).	Total water used (grams).	Initial area (sq. cm.).	Final area (sq. cm.).	Average area (sq. cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
1	8,918	600	300	...	8,442	1,376	414.0	1,601.7	1,007.8	136	286.9
2	8,360	500	180	...	8,081	959	414.0	1,620.8	1,017.4	94	291.5
3	8,233	500	120	...	7,885	968	414.0	1,614.4	1,014.4	95	290.0
4	8,221	500	0	...	7,860	861	414.0	1,544.0	979.0	88	272.9
5	8,237	500	0	...	7,927	810	414.0	1,436.1	925.0	87	246.8
6	8,316	500	138	...	8,004	950	414.0	1,596.7	1,005.4	94	285.6
	....	.....	.....	.....	....	....	....	....	....	99	278.9
ELYMUS CANADENSIS.											
1–31	5,273	100	0	...	5,186	187	145.4	492.6	319.0	59	238.8
2–40	5,010	100	100	...	4,896	314	187.6	635.7	411.6	76	238.8
3–41	5,010	100	100	...	4,916	294	192.3	651.6	421.9	69	238.8
4–28	5,206	100	0	...	5,070	236	131.3	445.0	288.1	82	238.8
5–43	5,180	100	100	...	5,044	336	201.7	683.3	442.5	76	238.8
Control.	5,093	0	0	...	5,087	6	.....	.....	.....	..	238.8
Aver....	....	.....	.....	.....	....	....	....	....	....	72	238.8
ACER NEGUNDO.											
1	4,355	...	...	...	4,306	49	38.6	67.6	53.1	92	75.1
2	6,104	...	...	...	6,049	55	42.2	107.6	74.9	72	155.5
3	5,910	...	...	...	5,872	38	36.2	45.6	40.9	93	25.9
4	6,363	...	80	...	6,300	143	99.2	241.2	170.2	84	143.1
5	5,933	...	...	...	5,878	55	58.8	72.6	65.7	84	23.4
Aver....	....	.....	.....	.....	....	....	....	....	....	85	84.6

daily evaporation, which was only 8.4 c. c. per day, in contrast to a normal daily loss of 20 to 30 c. c. during this portion of the growing-season (table 41).

Transpiration and Increase in Leaf-area.

The behavior of plants of the four species with respect to water-loss and increase in area during the control period of two weeks at Lincoln is exhibited in table 41.

Conditions and Results at Phillipsburg.

Installation.

Plants of the same species as those used in the preceding experiment were grown at Lincoln and shipped to the mixed-prairie station at Phillipsburg, where they were used experimentally for the 14-day period from June 18 to July 3. Some differences in the age and size of the various species from those at Lincoln were brought about by more or less favorable growing conditions during the few weeks preceding the beginning of the experiments, but the several species were as nearly as possible comparable with those previously used. The same methods were employed in both cases.

Physical Factors.

The period June 19 to July 3 was one of fairly typical weather for early summer at this station, when compared with that of the three preceding years for which factor data were obtained. Eight days were clear, except for a few floating clouds, and the sun shone on four others for over half of the time. Two days alone were sufficiently cloudy so that the sun shone for less than one-third of the day. Heavy showers occurred at night on June 18, 21, 26, and 29, as well as during the day on June 21, when it was necessary to cover the plants for 2 hours. Three days were so extremely hot, windy, and dry that it was desirable to shade the plants and protect them from the wind for periods of 2 to 5 hours. Notwithstanding an adequate holard, partial wilting occurred at these times, crop and ruderal plants suffering likewise. During one of the most severe days (June 24) the temperature was 98° F. and the humidity 42 per cent, while a south wind of 20 to 30 miles per hour was blowing. The air-temperature during the first five days of the period ranged from 65° to 98° F. and the humidity from 41 to 97 per cent. For the remainder of the time the variations were from 42° to 90° F. and 34 to 100 per cent humidity. The average day temperature for the period was 80.6° F. and the average day humidity 60 per cent. Soil temperatures at a depth of 6 inches varied from 74° to 82° F.

The total wind movement at a height of 39 cm. during the 14-day period was 1,100 miles, an average of 3.3 miles per hour; moreover, most of this occurred during the day. The somewhat xerophytic conditions are indicated by the average daily evaporation of 25.5 c. c. Under these conditions of prevailingly clear, warm weather, growth was marked and the losses by transpiration were high (table 42).

Conditions and Results at Burlington.

Installation.

The plants used at Burlington were also grown in appropriate containers at Lincoln for the usual period and shipped to Burlington, where they were used

experimentally for the 14-day period from July 6 to 20. Methods similar to those utilized for the other stations were employed throughout. Owing to the abundance of grasshoppers, it was necessary to screen the inclosure, a fence of hardware cloth about 4 feet high, the top edge of which was turned outward and downward, being employed. This modified the conditions of wind and evaporation within to a considerable extent and shaded the plants for about 2 hours each day.

Transpiration and Increase in Leaf-area.

Table 42.—*Water-loss and growth at Phillipsburg.*

Container.	Initial weight, June 19 (grams).	Water added (grams). June 23.	June 26.	June 30.	July 2.	Final weight, July 3 (grams).	Total water used (grams).	Initial area (sq. cm.).	Final area (sq. cm.).	Average area (sq. cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
Helianthus annuus.												
1	6,862	50	200	300	200	6,627	985	65.89	860.86	463.38	212	1,206.5
2	6,974	50	200	300	200	6,639	1,085	52.84	925.73	489.29	222	1,651.9
3	7,030	50	200	300	200	6,724	1,056	57.11	934.08	495.59	213	1,535.6
4	7,036	50	200	300	200	6,628	1,158	53.75	727.39	390.57	296	1,253.3
5	7,061	50	200	300	200	6,797	1,014	54.91	870.29	462.60	219	1,484.9
6	7,058	50	200	300	200	6,718	1,090	51.29	960.98	506.14	215	1,773.6
7	7,045	50	200	300	200	6,760	1,035	50.39	945.36	497.88	208	1,776.1
8	7,074	50	300	400	200	6,717	1,307	91.86	1,133.60	612.73	213	1,134.0
Aver.....	......	.....	.....	.....	.....	......	......	....	....	....	225	1,476.9
Avena sativa.												
1	8,388	200	350	400	200	8,138	1,400	316.37	1,254.24	785.31	178	296.4
2	8,385	150	350	300	200	8,210	1,175	260.54	905.84	583.19	201	247.6
3	8,442	200	350	400	200	8,200	1,392	353.59	1,297.50	825.55	169	266.9
4	8,121	100	350	300	200	8,053	1,018	353.59	836.16	594.88	171	136.4
5	8,369	200	350	400	200	8,129	1,390	353.59	1,239.82	796.71	174	250.6
6	8,211	100	350	400	200	7,958	1,303	316.37	1,196.56	756.47	172	278.2
Aver.....	......	.....	.....	.....	.....	......	......	....	....	....	178	246.0
Elymus canadensis.												
1	5,048	100	200	200	...	4,900	648	214.08	720.90	467.49	139	236.7
2	5,289	200	400	300	...	4,939	1,250	214.08	780.54	497.31	251	264.6
3	5,422	100	300	100	...	5,172	750	214.08	763.50	488.79	153	256.6
4	5,291	200	400	300	...	4,913	1,278	214.08	789.06	501.57	255	268.6
Check....	4,741	...	...	...	...	4,733	8	......	......	......	...	.....
Aver.....	......	.....	.....	.....	.....	......	......	....	....	....	199	256.6
Acer negundo.												
1	6,190	...	200	100	...	6,068	422	128.94	336.70	232.82	181	161.1
2	6,079	...	100	50	...	5,979	250	77.52	214.99	146.26	171	177.3
3	4,337	50	100	100	...	4,208	379	139.28	393.41	266.35	142	182.5
4	4,349	50	100	100	...	4,260	339	124.81	285.53	205.17	165	128.8
5	6,022	...	100	...	...	5,956	166	59.17	157.24	108.21	153	165.7
6	5,955	...	100	...	...	5,878	177	69.38	179.46	124.42	142	158.6
Aver.....	......	.....	.....	.....	.....	......	......	....	....	....	159	162.3

Physical Factors.

The weather conditions for the first four days of the experiment were very characteristic of the high plains during July, with day temperatures reaching 90° to 96° F. and falling to 60° or 65° F. at night, while the humidity ranged from 25 to 30 per cent in the afternoon to 80 or 85 per cent at night. However, this was followed by 10 days during which the atmosphere was more humid and cooler, due largely to an unusual amount of cloudy weather and rain. Rains fell in the evening or at night as follows: July 11, 0.02 inch.; 14th, 1.48 inches; 16th, 0.51 inch; 17th, 0.58 inch. Moreover, the heavy rains were general and greatly increased the humidity. One day was entirely cloudy, and four were cloudy half or more of the time, while on 3 others the sky was overcast more than one-fourth of the time, only 6 days being clear. With the exception of the first 4 days, clouds invariably obscured the sun after 5 or 6 p. m.

The temperature ranged rather uniformly between 55° to 60° and 80° to 85° F., and the humidity usually reached 100 per cent at night (the vegetation being covered with rain or dew) and fell to 50 to 55 per cent during the afternoon (on one day to 36 per cent). The average day temperature and humidity for the period from 8 a. m. to 6 p. m. were 80° and 57 per cent respectively. While the temperature was nearly the same as the average day temperature for the same period during the three preceding years, as determined by hygrothermographs in the field, the humidity was 11 per cent higher. The soil temperature at a depth of 6 inches among the containers was 73° to 86° F.

The wind movement at a height of 39 cm. during the first 4 days averaged over 7 miles per hour, but for the rest of the time it was much less (3.4 miles per hour). The average daily evaporation was 35.4 c. c., which was 5 c. c. lower than for the same period of the preceding years. It was necessary to shade the plants for an hour or so to prevent wilting during the first day or two.

Transpiration and Increase in Area.

Table 43.—*Water-loss and growth at Burlington.*

Helianthus annuus.

Container.	Initial weight, July 6 (grams).	Water added (grams).					Final weight, July 20 (grams).	Total water used (grams).	Initial area (sq. cm.).	Final area (sq. cm.).	Average area (sq. cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
		July 11.	July 13.	July 16.	July 18.	July 19.							
1	6,526	100	100	300	300	300	6,444	1,182	30.62	1,235.16	632.89	187	3,933.9
2	7,572	100	100	300	300	300	7,637	1,035	22.22	775.20	398.71	259	3,388.7
3	6,591	100	100	300	300	300	6,409	1,182	29.59	1,159.44	594.52	199	3,818.4
4	7,538	100	0	300	300	300	7,617	921	21.58	650.91	336.25	274	2,916.2
5	7,599	100	0	300	300	300	7,612	987	20.20	802.33	411.27	240	3,871.7
6	6,600	100	100	300	300	300	6,517	1,183	26.10	1,314.35	670.23	176	4,935.8
7	6,692	100	100	300	300	300	6,522	1,270	21.91	1,354.01	687.96	185	6,079.9
8	7,545	100	100	300	300	300	7,500	1,145	27.78	868.16	447.97	256	3,023.7
9	6,477	100	0	300	300	300	6,446	1,031	28.17	1,114.18	571.18	181	3,855.2
10	6,636	100	0	300	300	300	6,754	882	18.22	955.05	486.64	181	5,141.7
Aver.	......	.....	.....	.....	.....	.....	......	......	......	....	....	214	4,096.5

TABLE 43.—*Water-loss and growth at Burlington*—Continued

AVENA SATIVA.

Container.	Initial weight, July 6 (grams).	Water added (grams). July 11.	July 13.	July 16.	July 18.	Final weight, July 19 (grams).	Total water used (grams).	Initial area (sq. cm.)	Final area (sq. cm.).	Average area (sq. cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
1	8,850	200	...	250	200	8,722	778	92.92	566.94	329.93	236	510.1
2	8,732	150	100	200	150	8,593	739	100.33	721.32	410.83	180	618.9
3	8,702	150	100	200	200	8,583	769	85.48	642.81	364.15	211	652.0
4	8,803	100	100	150	100	8,734	519	38.93	506.17	272.55	190	1,200.0
5	8,915	150	100	200	200	8,816	749	89.21	523.91	306.56	244	487.3
Check........	8,742	...	...	...	...	8,734	8	.....	......	......	...	.....
Average......	......	.....	.....	.....	.....	......	......	......	....	....	212	693.7

ELYMUS CANADENSIS.

Container.	Initial weight, July 6 (grams).	Water added (grams). July 11.	July 13.	July 16.	July 18.	Final weight, July 20 (grams).	Total water used (grams).	Initial area (sq. cm.).	Final area (sq. cm.).	Average area (sq. cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
1	5,253	...	100	0	50	5,211	192	47.10	176.87	111.98	172	275.5
2	5,277	...	100	100	50	5,226	301	88.81	212.08	150.45	200	138.8
3	5,197	...	100	50	50	5,159	238	64.98	155.25	110.12	216	138.9
4	5,158	...	100	100	50	5,110	298	74.18	175.53	124.86	239	136.6
5	5,336	...	100	50	50	5,284	252	59.15	132.02	95.58	264	123.2
Average......	....	.....	.....	.....	.....	......	......	......	....	....	218	162 6

ACER NEGUNDO.

Container.	Initial weight, July 5 (grams).	Water added (grams). July 9.	July 13.	July 16.	July 18.	Final weight, July 19 (grams).	Total water used (grams).	Initial area (sq. cm.).	Final area (sq. cm.).	Average area (sq. cm.).	Loss per sq. dm. (grams).	P. ct. increase in area.
1	6,112	100	0	150	50	6,055	357	134.50	375.84	255.17	139	179.4
2	5,995	0	100	50	50	5,986	209	70.54	234.11	157.33	137	231.8
3	4,384	150	0	150	100	4,300	484	163.83	584.06	373.95	129	256.5
4	4,339	200	100	150	150	4,252	687	283.08	737.99	510.54	134	160.7
5	4,355	150	100	150	150	4,290	615	218.84	685.40	452.12	136	213.2
6	4,194	100	100	100	100	4,151	443	125.58	475.71	300.65	147	278.8
Average......	......	.....	.....	.....	.....	......	......	......	....	....	137	220.1

Table 44.—*Transpiration and growth at the stations.*

Species.	Water-loss per sq. dm. (grams).			Increase in area (p. ct.).			Rate of growth, based on actual increase in area (p. ct.).		
	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.
Sunflower	145	225	214	409	1,477	4,097	854	860	998
Wild rye	72	199	218	239	257	163	410	549	140
Oats	99	178	212	279	246	694	1,155	796	510
Box-elder	85	159	137	85	162	220	52	161	370
Average	100	190	195	253	535	1,294	618	591	504

Table 45.—*Environmental conditions at the stations.*

Station.	Approximate hours sunshine.	Average day temp. (° F.).	Soil temp. (° F.)	Average day humidity (p. ct.).	Average daily evaporation (c. c.).	Wind per hour (miles).
Lincoln	39	70.1	62 to 71	75	8.4	3.6
Phillipsburg	75	80.6	74 82	60	25.5	3.3
Burlington	71	80.0	73 86	57	35.4	3.4

Summary and Conclusions.

This onerous series proved a disappointment in so far as normal climatic relations were concerned, owing to the wholly exceptional weather. This is revealed by table 45, and is brought out even more graphically by comparing the data here with those obtained during other years. The amount of sunshine at Lincoln was little more than half that at the other stations, while the air-temperature averaged 10° lower and the soil temperature ranged from 11° to 15° lower. The average humidity was 15 to 18 per cent higher and the evaporation but a third or a fourth of that at Phillipsburg or Burlington. Hence, it is easy to understand why the increase in area was twice as great at Phillipsburg and more than four times as great at Burlington though the normal relation is suggested by the rate of growth based on the actual increase in area and by the order of water-loss at the three stations. Thus, while the plant responses are in agreement with the physical factors for the respective fortnights concerned, it is obvious that entirely comparable results could be insured only by dealing with the growth season for each species. An adequate record of transpiration and growth for such a period at stations widely separated demands at least one resident investigator for each station, and such studies must await the future.

TRANSPIRATION AND GROWTH OF COMMUNITIES.

Transpiration from Natural Cover and Crops.

Objectives.

One of the major tasks of quantitative ecology is to determine the functional responses of plants when grouped in communities. While much light can be obtained by the use of individual plants under control in the field, in the form

of standard phytometers, these differ essentially in their soil and competition relations from plants growing together in the actual cover. Hence, the task is to maintain these natural relations of the community and at the same time to secure a degree of control that modifies the efficient factors little or not at all. In the case of transpiration, for example, these requisites can be met only by weighing, as all other methods modify the physical factors to an undesirable degree. The method that maintains the soil and community relations with the minimum disturbance is the soil-block, which was first employed for determining the chresard in the field (Clements, 1904, 1905). This requires only such slight modifications as those of size and form to become applicable to all problems in which an undisturbed soil-root core is indispensable.

In consequence, the first objective was to perfect the soil-block method so that it could be used in the field with both convenience and accuracy. Because of its importance in the grassland climate, the chief function to be measured was transpiration, though chresard and aeration can be studied with something of the same readiness. In the present case the transpiration from representative cores was followed in the proper climate of each association, but it is evident that the containers can be moved or exchanged between different edaphic or climatic stations and thus serve as reciprocal phytometers. This permits the determination of the transpiration behavior of each climax in its own climate in terms of adjustment and adaptation and at the same time affords a basis for comparing adjacent climaxes. A further use of fundamental value arises out of the rainfall relation. The method of the soil-core not only makes it possible to trace the complete water-cycle of rainfall, holard, evaporation, and transpiration, but also to estimate the extent to which the vegetation of each region may furnish the water-vapor for its own rainfall (Clements, 1923). Finally, it also opens up a new field in the functional relation of roots to the soil as an actual structure, which shows striking differences from climate to climate, as well as from one local habitat to another.

Methods.

A steel cylinder 12 inches tall and with an inner area of 1 square foot, the lower edge of which was sharpened, was driven into the grassland soil to a depth of 4 inches. Care was taken to cut off none of the leaves belonging to the plants in the square foot selected, which was chosen with a special regard to its representative structure. The cylinder was then carefully removed, leaving the column of soil intact, and replaced by one of heavy galvanized iron 3 feet long and reinforced at both ends by a heavy wire over which the metal was turned back smoothly. After starting a row of these cylinders at distances of 8 inches, a trench 2 feet wide was dug around them to a depth of over 3 feet. In this process no soil was removed within 3 or 4 inches of the cylinder. As the trench was deepened, the columns of soil were carefully pared away with large knives in such a manner that the cylinders could be forced down under considerable pressure from above. By shaping the column for a few inches in front of the descending cylinder, it was possible to force the latter into place over a tightly fitting soil-core to a depth of 3 feet. The columns were then undercut and smoothed off level with the lower end of the cylinder. A loose-fitting metal bottom with the edges 2 inches deep was

placed over the end and the entire container was then weighed on a portable Fairbanks scale sensitive to one-fourth pound.

In the meantime, a trench sufficiently wide and deep to receive the cylinders in an upright position had been dug in a nearby area, care being taken not to cover the grass with soil. The containers were lowered in the new trench and slid into place on a plank in the bottom, after which the bottoms were made water-tight by means of a measured amount of hot wax of the usual composition. The trench was then filled with soil and pieces of sod were fitted around the tops so that the surface conditions would be essentially normal. The trenches were selected so that the surface water would readily drain away from them and in addition the plants were covered by wooden roofs whenever rain was actually falling. This was imperative because of the varying interception of rainfall by the different vegetation in the several containers. In the case of the cultivated crops, oats and millet, the usual type of bottom was replaced by one 3 feet deep, owing to the difficulty of selecting a proper slope for drainage. In order to determine the amount of water evaporated from the cultivated soil, the plants were removed from one container in each field. In another check, the natural grasses were left in place after having been killed by the addition of a measured amount of boiling water.

From time to time, depending upon the weather and the needs of the plants, water in measured amounts was slowly added to all the containers, and as a result there was little shrinkage of the core from the sides of the container. None of the plants died, and even those near the edges gave no signs of wilting, demonstrating that the roots in the core supplied abundant water for transpiration. Much care was exercised in watering, so that there was little or no run-off down the sides of the core. This was accomplished by pouring the water on slowly and pressing the moist soil firmly against the cylinder wherever the contact was not complete. At the end of the period the containers were again weighed and the losses calculated.

At the end of the experiment the vegetation was carefully removed at the soil surface by means of a hand grass-clipper. The dense foliage of former years was carefully separated from the living plants, the latter oven-dried at 60° C., and weighed.

True Prairie, Series 1.

Installation.—The first series consisted of 6 sod-cores which were installed on the high prairie during the period of May 31 to June 15. The group in container 2 consisted chiefly of a sod of *Andropogon nutans* and *Bouteloua racemosa,* in which were found 4 bunches of *Koeleria cristata.* Container 1 was very similar, having been taken within 18 inches from the former; the plants in it were killed with hot water and it was then employed as a control. The third group consisted mainly of *Andropogon nutans, A. scoparius,* and *Koeleria,* and container 4 resembled it closely. The group in container 5 comprised several bunches of *Stipa spartea,* 4 small clumps of *Bouteloua racemosa,* and 3 of *Andropogon scoparius;* No. 6 was occupied chiefly by *Stipa spartea* and *Andropogon scoparius.*

The entire period was exceptionally cool and wet, only one day being wholly sunny and the total sunshine being approximately only a third of the total daytime period. The average day temperature was 70° F. and the day

humidity 75 per cent. The unusual nature of the weather is perhaps best revealed by the fact that the average daily evaporation was only 8.4 c. c. in contrast with a normal loss of 20 to 30 c. c. per day during this period.

Results.—A striking character of the soil columns is their rather uniform weight. Cores 1 to 4 were obtained from a single trench, the extreme distance between the containers not exceeding 6 feet. The weight of the 3 cubic feet of soil (exclusive of container) varied only from 289 to 295 pounds. Soil columns 5 and 6 were obtained about 50 feet distant from the first trench.

TABLE 46.—*Water-losses from sods in high prairie, Lincoln, Nebraska.*

Container.	Original weight, May 31.	Weight of seal.	Water added May 31.	Final weight, June 15.	Loss.	Dry weight of foliage.	Loss per gram of dry weight.
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*gm.*	*gm.*
1 (control).	309.50	0.60	5.5	312.5	3.1	.....	.....
2.........	307.00	0.60	4.0	303.0	8.6	19.18	203.4
3.........	305.25	1.20	4.0	302.0	8.45	18.95	202.3
4.........	303.75	1.00	4.0	302.5	6.25	13.88	204.3
5.........	313.00	0.80	4.0	311.0	6.8	18.95	162.8
6.........	308.00	1.20	4.0	308.0	5.2	15.18	155.4

The water-losses, though low, are fairly consistent, ranging from 2.1 to 5.5 pounds per square foot in excess of that of the area covered with dead grasses. Moreover, the variations are directly proportional to the extent of the grassy cover, as expressed in dry weight. The mixture of grasses (chiefly andropogons and *Koeleria*) lost about 203 grams of water per gram of dry matter, which was somewhat more than that from *Stipa spartea* (average 159 grams).

TRUE PRAIRIE, SERIES 2.

Installation.—Because of the unfavorable conditions during the first series, the experiment was repeated from July 24 to August 8, 5 containers being installed on the high prairie and 4 in the adjoining low prairie. In container 1 a mixture of *Andropogon nutans, Koeleria cristata,* and *Poa pratensis,* with a single plant of *Amorpha canescens* (*Andropogon* being most abundant), covered half of the area. These had an average height of 12 inches. The surface of three-fourths of the second container was covered principally with *Andropogon nutans,* but also with a mixture of *Koeleria cristata, Bouteloua racemosa,* and a little *Poa pratensis,* with an average height of 15 inches. The grasses in container 3 were chiefly *Andropogon scoparius,* with a third as much *A. nutans* and a very little *Bouteloua racemosa;* the height was 14 inches. In container 4, one-fifth only of the area was bare, the rest being occupied with a mixture of the grasses named above, *Andropogon scoparius* dominating. *Amorpha canescens* and *Antennaria campestris* were each represented by a single small clump. The control container, No. 5, in which the grasses were killed as usual, was very similar to No. 3.

In the low prairie two clumps of *Andropogon furcatus,* 22 inches in average height, occupied slightly less than half of the area in container 6, the rest being bare. Nearly two-thirds of the area in container 7 was bare, the rest being occupied by a large clump of *A. furcatus* 16 inches in height. *Spartina cyno-*

suroides and a little *Panicum virgatum*, with an average height of 38 inches, filled about one-third of container 8, the remainder being destitute of plants. The remaining cylinder was sunk and a soil-core obtained in a field of alfalfa where the plants were 21 inches high and beginning to blossom freely. A single clump in the center of the core was obtained which occupied only one-fourth of the area.

Because of a prolonged period of hot, dry weather, the grasses at both stations had rolled leaves and some of them wilted during the afternoons, a result rarely seen in the true prairie. However, the weather conditions for the following 15 days were below normal in the amount of sunshine and heat. Only 2 days were entirely clear and rain fell on 8 different days. The average day temperature was 79° F. and the average day humidity was 80 per cent. With respect to transpiration, conditions were much more nearly normal than in the preceding series, as is shown by the fact that the average daily evaporation was 22 c. c. in contrast to 8 c. c.

Results.—The losses per square foot in the upland prairie ranged from 9.4 to 13.7 pounds, as compared with 4.8 pounds from the control. In the low prairie the losses varied from 12.3 to 17.5 pounds, owing to the more luxuriant growth of the vegetation, while that from alfalfa was 21.5 pounds. Based on the quantity of water lost per dry weight, the upland prairie grasses show a relatively higher loss (maximum 332.5 gm.) than the coarser, larger-stemmed lowland species, where a maximum loss of only 165 gm. of water per gram of dry matter was found. On this basis the woody-stemmed *Spartina* transpired less even than the upland grasses. Alfalfa lost 442 grams of water per gram of dry matter.

TABLE 47.—*Water-losses from sods and from alfalfa, Lincoln, Nebraska.*

Container.	Original weight July 24.	Weight of seal.	Water added.						Final weight Aug. 8.	Loss.	Dry weight of plants.	Water lost per gram dry weight of plants.
			July 25.	July 26.	July 28.	July 30.	Aug. 1.	Aug. 3.				
	lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*gm.*	*gm.*
1.......	294.75	0.61	2	2	3	3	2	2	300	9.36	12.77	332.5
2.......	294.50	1.22	2	2	3	3	2	2	296.0	13.72	32.07	194.1
3.......	291.25	1.08	2	2	3	3	2	2	295.0	11.33	23.12	222.3
4.......	286.25	0.81	2	2	3	3	2	2	291.25	9.81	22.70	196.0
5 (check)	293.75	0.81	4	2	1	3	1	0	300.75	4.81	......	....
6.......	308.75	2.03	5	4	5	2	2	2	313.25	17.53	66.53	119.5
7.......	291.00	0.81	5	4	5	2	2	2	296.5	15.31	42.17	164.7
8.......	322.00	2.03	5	4	5	2	2	2	331.75	12.28	56.07	99.4
9.......	307.50	2.03	5	7	5	3	2	2	312.0	21.53	22.09	442.1

MIXED PRAIRIE.

Installation.—At Phillipsburg 6 cylinders were used in the mixed prairie and 3 in an adjoining field of oats. Container 2 was two-thirds occupied by a dense sod of *Bouteloua gracilis* with a very little pistillate *Bulbilis dactyloides;* these had an average height of 9 inches. The third container was fully two-thirds covered by a practically pure growth of *Bouteloua gracilis* with an average height of 9 inches, in which were found a few stalks of *Sporobolus cryptandrus* and one small *Callirrhoe involucrata.* The control, No. 1, bore a vegetative cover of a kind and density almost exactly like that in No. 3.

About one-fourth of the area in container 4 was bare; the rest was covered with a dense sod of pistillate *Bulbilis dactyloides* 4 to 8 in. tall. There were also four small clumps of *Carex filifolia* and a very small amount of *Bouteloua gracilis.* A fine clump of *Andropogon furcatus*, 18 inches in average height, occupied 96 square inches of the area in container 5, the rest being devoid of vegetation. Container 6 also bore a clump of the same grass 91 square inches in extent at the base and with an average height of 20 inches.

The period from June 18 to July 3 was typical of early summer at this station, as shown by the factor data for the preceding years. Except for a few clouds, 9 days were clear and 4 others were sunny for more than half of the time. The average day temperature was 80.6° F. and the average day humidity was 60 per cent. The effect of the factors concerned in transpiration is indicated by the average daily evaporation, which was 25.5 c. c.

Results.—Among the short-grasses the amount of water added slightly exceeded the amount used; it was approximately the same in amount in the oats, but the soil lost 3 to 7 pounds of its original weight in the case of the bluestems. The losses from the control with a dead short-grass cover and from bare soil were 4.4 and 7.2 pounds respectively. Those from containers 2 and 3, where the dominants were grama grass, were 14.7 and 16.2 pounds per square foot respectively, or approximately 1 pound (pint) of water per day. The buffalo-grass sod lost nearly as much, 14.2 pounds, while loss from the big bluestem was nearly twice as great, 27 and 28 pounds respectively. The oats, even in the late stage of development, lost practically the same amount of water as the short-grasses (14.7 and 16.4 pounds).

Table 48.—*Water-losses from sods and oats, Phillipsburg, Kansas.*

Container.	Dominant species.	Original weight, June 18.	Weight of seal.	Water added.					Final weight, July 3.	Loss.	Dry weight of plants.	Loss per gram of dry weight.
				June 18.	June 19.	June 22.	June 26.	June 30.				
		lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*gm.*	*gm.*
1	Control, dead Bouteloua gracilis.........	276.25	0.9	7	0	1	2	4	286.75	4.40	.....	.....
2	B. gracilis....	278.75	0.9	2	2	4	4	4	281.00	14.65	19.30	344.3
3	Do.......	274.00	1.2	2	2	4	4	4	275.00	16.20	20.42	359.9
4	Bulbilis dactyloides.......	275.50	0.75	2	2	4	4	4	278.00	14.25	21.76	297.0
5	Andropogon furcatus.....	282.50	0.9	2	2	4	4	4	271.25	28.15	53.90	236.9
6	Do.......	282.30	0.75	2	2	4	7	4	275.00	27.05	53.94	227.5
7	Oats..........	269.25	2.43	0	2	4	4	4	271.00	14.68	34.30	194.1
8	Do	267.50	2.43	0	2	4	4	4	267.5	16.43	36.43	204.6
9	Control, bare soil.........	285.75	2.43	0	2	1	2	2	288.00	7.18	.. ..	.. .

Short-grass Plains.

Installation.—The experiments in the short-grass plains were carried out at Burlington from July 5 to 20. Six containers were used in the grassland and three in an adjoining field of millet. Container 2 was covered with a dense closed mat of nearly pure pistillate *Bulbilis dactyloides*, except for about one-sixth of *Bouteloua gracilis.* This formed a fine green carpet 4 inches in height. Only one-fifth of the area inclosed by the cylinder was bare. The check container, No. 1, in which the vegetation was killed, was similar, except

that one-fourth of the area was bare. Container 3 was very much like No. 1, except for a mixture of about one-third grama, which was flowering at a height of 8 inches. The average height of the short-grass foliage was 4.5 inches. Container 4 consisted of nearly pure pistillate *Bulbilis* about 4 inches tall, with just a little grama, some of which had flower-stalks; only one-sixth of the area was bare. Containers 5 and 6 had a rather dense growth of *Agropyrum glaucum*. The foliage averaged 20 inches in height, most of the stems being dry and yellowish to a height of 6 or 8 inches. There were no flower-stalks. The two containers were very similar, No. 6 having slightly less vegetation. The millet was about 4 weeks old, of thick stand, and had an average height of 18 inches. It had not begun to head at the beginning of the experiment (July 5), but by the end of the 15-day period it was well headed at an average height of 20 inches. Two containers with millet were used, and one from which the crop had been removed by pulling out the plants.

The weather during the period was rather exceptional for July on the high plains, only 7 of the 15 days being entirely clear. The average day temperature was 80° F. and the average day humidity was 57 per cent. While the temperature was much the same as that for this period during the 3 preceding years, the humidity was 11 per cent higher. The average daily evaporation was 35.4 c. c. as compared with 40.5 c. c. for the same period in previous years.

Table 49.—*Water-losses from sods and millet, Burlington, Colorado.*

Container.	Dominant species.	Original weight, July 5.	Weight of seal.	Water added, July—									Final weight, July 20.	Loss.	Dry weight of plant.	Loss per gram of dry weight
				5.	6.	7.	8.	9.	12.	17.	18.	19.				
		lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*gm.*	*gm.*
1	Control, dead Buffalo grass....	254.75	2.03	5	0	0	2	0	3	3	0	1	265.75	5.03	.....	.....
2	Same, living	260.5	1.22	2	2	0	3	0	3	3	0	2	264.25	12.47	15.4	367.3
3	Do...	254	1.22	2	2	0	3	0	3	3	0	2	259.00	11.22	17.75	286.7
4	Do...	265.25	1.22	2	2	0	3	0	3	3	0	2	268.75	12.72	15.75	366.3
5	Wheat grass....	251.5	1.22	4	2	2	3	0	4	3	0	2	254.00	18.72	45.31	187.4
6	Do...	254.25	1.08	4	2	2	3	0	4	3	0	2	258.50	16.83	40.32	189.3
7	Millet.....	274.78	1.22	0	2	2	3	2	3	3	3	2	274.50	21.50	46.95	207.7
8	Do...	278.75	1.22	0	2	2	3	0	3	3	3	2	279.00	18.97	40.20	214.2
9	Control bare soil.	267.25	1.22	0	1	1	2	0	3	3	0	0	271.50	6.97	.....	....

Results.—The final weights of the containers were only slightly greater than their original weights, which means that approximately all of the water added was again lost by transpiration or direct evaporation from the soil and dead plant surfaces. The latter amount was only 5.03 pounds (container 1). The square foot of *Bulbilis* and *Bouteloua* in each of the three containers lost 11 to 13 pounds. The wheat-grasses lost 17 to 19 pounds, varying directly with the amount of foliage concerned, while the losses from the millet were even greater, 19 to 21.5 pounds. It is interesting to note that the bare area lost approximately 2 pounds more water than a similar area covered with dead grasses. The loss of water in grams per gram of dry weight of the vegetation is almost identical (about 366 grams) in containers 2 and 4, the smaller ratio in No. 3

probably being due to the presence of flower-stalks of grama grass, which increased the dry weight but transpired little. The relatively low ratio of the wheat-grasses (188 grams) may readily be explained when their large, very fibrous stems are considered. Losses from the millet were intermediate, probably being relatively less than earlier because of the heads.

Considered solely on the basis of loss per square foot, the millet ranks first, wheat-grass second, and the short-grasses last. Thus, as is shown by the distribution of the native species, wheat-grass is less adapted to this semiarid region than are the short-grasses, more than one-third more water escaping from the area occupied by the former. These data, however, hold only for the conditions of the experiment, viz, with the plants growing in very dry soil and under unusual humidity for the Great Plains. This is clearly brought out by a comparison of the physical factors with those of preceding seasons.

Summary.

Transpiration from natural cover.—As in the case of water-loss from the phytometers, the exceptional weather of the summer obscured the normal climatic response of the sod-cores. When the physical factors and the type of vegetation are taken into account (table 50), it is clear why the low short-grass cover at Burlington in the driest climate transpired less than the mixed prairie at Phillipsburg in a moister atmosphere, and more than the luxuriant true prairie at Lincoln in a much more humid climate. Thus again, while the use of sod-cores contributed no clear-cut evidence as to the relation of the three climaxes and their climates, it does demonstrate the value of the method and what can be expected of it when employed through a series of years. The losses from the three crops, while of interest, have no comparative value, since a different species was used at each station; they are distinctly helpful, however, in showing the similarity in the behavior of the native cover and representative crops for each station and in potential importance for the rainfall of each region. However, in the future development of the method it is obvious that the same dominant and the same crop should be employed throughout the series of stations, and this should involve the reciprocal transfer of sod-cores and crop-cores between the three stations.

Table 50.—*Comparison of factors and average water-loss.*

Station.	Dominant grasses.	Date of experiment.	Approximate sunshine.	Average day temperture.	Average day humidity.	Average daily evaporation.	Average daily loss from sq. ft. of cover.
			p. ct.	*° F.*	*p. ct.*	*c. c.*	*lbs.*
Burlington....	Bulbilis..... Bouteloua... Agropyrum..	July 5 to July 20	71	80	57	35.4	0.96
Phillipsburg...	Bouteloua.... Andropogon..	June 18 July 3	75	80.6	60	25.5	1.33
Lincoln.......	Andropogon. Stipa....... Koeleria..... Bouteloua...	July 24 to Aug. 8	47	79	80	22.0	0.85

Growth of Natural Cover and Crops.

Objectives.

The growth of a representative area of a community may be used as a climatic index as well as a measure of response in much the same way as transpiration. It possesses three distinct advantages over the latter, though the two are complementary and hence one can not replace the other. Growth demands no laborious installation, as it can be determined directly from the native or culture community in position. While it can be measured at any time, it yields the major values at the end of the growing-season, and thus does not require the services of a resident investigator. Moreover, it integrates the response for the whole season, though as a complex it permits less ready analysis than transpiration and is also less satisfactory for short periods. In short, it is the simplest and most convenient of all community phytometers when employed in the form of the clip-quadrat. This is the only practicable method, as the measurement of the individuals in a community group is too time-consuming to be desirable. There are certain cases in which it is profitable to pull the individuals out with their roots, but this is hardly feasible in a close cover or a compact soil. The clip-quadrat is merely the usual one of a square meter in extent, from which the shoots are cut at any desired time. It may be either smaller or larger in order to meet special conditions, as in the case of crops planted in rows. The growth is regularly expressed in terms of dry matter, but in the case of grazing ranges or forage crops, the green weight should likewise be found. Finally, the clip-quadrat facilitates the analysis of community response to climatic factors by making it possible to measure growth during different portions of the season or its variations from season to season or from the wet to the dry phase of a climatic cycle, and to determine the part played by the various species in the total production.

In the case of the grains, it is often preferable to select the individuals to be cut in accordance with the results desired, instead of taking all those in a particular area (Weaver, Jean, and Crist, 1922). This may be regarded as an aggregate clip-quadrat; it has the further advantage of permitting measurement of particular individuals throughout the season.

Plan.

Clip-quadrats were first installed at the three stations in 1920; these represented high and low prairie in the true-prairie association, mixed prairie, and short-grass plains. They were again cut in 1921 and 1922 to determine the fluctuation from year to year. The first step in the simple procedure was to select a considerable number of quadrats in typical areas of each climax. The height and density of the cover, the abundance of dominant and subdominant species, the presence of layers, etc., were recorded and photographs made of certain of the quadrats. In some instances it has proved desirable to make a chart of these as well. The cover was then removed by cutting it near the surface and at a uniform level with a hand-clipper. It was collected, sorted, and then shipped into the laboratory to be thoroughly air-dried, after which the actual production was determined on the basis of the dry weight. This gave an expression of the growth of the community as a unit, as well as the rôle taken by each dominant or subdominant in this. As complete factor

records were obtained at each station, this made it possible to correlate the yield of community or species with the climate and the season at each. The physical factors for the several years have been given in the preceding chapters and hence are not repeated here.

Since even the most uniform cover shows some variation in density, the clip-quadrats were selected with much care and in sufficient number to insure dependable results. As in all ecological studies that are adequate, i. e., causal and quantitative, rather than merely mathematical, this demands considerable knowledge of the community and can not be met by random selection. The best plan is to locate a proper proportion of quadrats in pure or nearly pure stands of each dominant whenever these are present and to distribute the others among the various mixtures. It is often desirable to take the subdominants into account in doing this, as their yield may be much greater than that of the grasses.

Results for 1920.

The growth response for this year was obtained from about 400 clip-quadrats, of which 50 were in the true prairie at Lincoln, 50 from mixed prairie at Phillipsburg, 50 from the short-grass plains at Burlington, and 30 from each of the cultivated fields at the various stations. The short-grasses at Burlington averaged 103 gm., those at Phillipsburg 290 gm. Wheat-grass (*Agropyrum glaucum*) at Burlington yielded 398 gm. per square meter, while at Phillipsburg the yield was 480 gm. A mixture of short-grass and tall-grasses gave 244 gm. per square meter at Burlington and 470 gm. at Phillipsburg, and the mixed prairies at Phillipsburg produced a total yield of 439 gm. per square meter, while those at Lincoln averaged 452 gm. The average yield at Phillipsburg (439 gm.) exceeded that from the hilltops at Lincoln (361 gm.) or even the slopes (429 gm.) at this time (July 9), but did not equal that of the lowland, which was 564 gm. Moreover, an examination of the factor data shows that late-summer drought usually prevails at the western stations and good plant growth is not maintained. This is well illustrated by a second series of quadrats cut August 16 to 24. The average yield at Burlington was 196 gm. (more mixed short and tall grass quadrats being included than before), at Phillipsburg 310 gm., and at Lincoln 465 gm. On the basis of the 50 quadrats taken at each station during the season, the average total production, proceeding from the drier western station eastward, was 183, 378, and 458 gm. respectively.

Crops of oats (*Avena sativa*), spring wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), alfalfa (*Medicago sativa*), and white sweet clover (*Melilotus alba*) were grown in plats adjoining the several grassland stations (Weaver, Jean, and Crist, 1922: 76). Each kind of crop was planted from the same lot of seed and grown under conditions of farm practice common to the several localities respectively. The crop plants were thoroughly air-dried before weighing, and the relative height of the mature oats and wheat at the several stations, as well as the comparative yield from an average square meter, were determined. The yield is the average of 25 to 30 square-meter quadrats taken from each of the several plats at the three stations when the grain was ripe. 400 plants of alfalfa and 300 of sweet clover of average size were carefully selected at each of the stations, cut at the ground-line, thoroughly air-dried, and the dry weight ascertained. This was done during July and again in

August for the sake of obtaining comparative values between clip-quadrats and a group of selected plants (table 51).

The height-growth of all crops was greatest at Lincoln, less at Phillipsburg, and least at Burlington, the height of the former averaging more than twice that of the latter. The maximum penetration of roots was usually greatest at Phillipsburg, next at Lincoln, and least at Burlington, a divergence readily explained by the greater holard at the first and the dry subsoil and hard-pan at the last.

TABLE 51.—*Growth and yield of crop-quadrats and plants, 1920.*

Crop and station.	Date of harvest.	Average height.	Maximum depth of roots.	Average yield in grams per sq. meter.	Weight of 1,000 kernels.
Oats:		*feet.*	*feet.*		*gm.*
Lincoln	July 12	3.0	4.8	706	20.1
Phillipsburg	July 20	2.6	6.0	379	16.6
Burlington	July 19	1.5	2.7	175	16.2
Wheat:					
Lincoln	July 15	3.2	4.8	740	29.8
Phillipsburg	July 20	2.3	5.8	322	9.1
Burlington	July 19	1.7	2.7	205	20.1
Barley:					
Lincoln	July 12	2.7	5.4	607	32.7
Phillipsburg	July 17	2.4	6.7	407	14.7
Burlington	July 19	1.7	2.9	176	23.9
Alfalfa:				Dry weight of plants.	
Lincoln	July 12	1.5	5.7	528	....
Phillipsburg	July 9	0.7	5.0	292	....
Burlington	July 8	0.4	2.3	122	....
Sweet clover:					
Lincoln	July 12	2.0	5.5	840	....
Phillipsburg	July 9	1.3	5.7	461	....
Burlington	July 8	0.4	2.8	213	....
Alfalfa:					
Lincoln	Aug. 9	1.8	5.9	739	....
Phillipsburg	Aug. 4	1.2	...	601	....
Burlington	Aug. 5	0.6	2.0	214	....
Sweet clover:					
Lincoln	Aug. 9	2.5	...	1,103	....
Phillipsburg	Aug. 4	1.7	...	869	....
Burlington	Aug. 5	0.8	2.7	323	....

The average yield of grain for the three cereals was about twice as much at Lincoln as at Phillipsburg, and nearly twice as much at the latter as for Burlington. A similar relation obtained for the first cutting of alfalfa and sweet-clover, but at the second cutting Phillipsburg more nearly approached Lincoln. Thus, the five crops decreased decisively in both height and yield from Lincoln westward in correspondence with the rainfall, holard, and humidity.

RESULTS FOR 1921.

Two series of cuttings were made during 1921, one about July 1 and a second during the last half of August. Ten clip-quadrats each of *Bulbilis dactyloides* and *Agropyrum glaucum* were used at each of the stations early in the summer; at all of these both grasses had headed or blossomed at the time of cutting.

The buffalo-grass averaged about 4.5 inches high at Burlington, while the staminate spikes were 5.5 inches tall. In the mixed-prairie the foliage of this grass averaged 5 inches in height and the flower-stalks 6 inches. *Bulbilis* occurs in the prairies at Lincoln only where the tall-grasses are held in check by grazing; hence it was impossible to secure an ungrazed sod comparable to that at the other stations. The foliage was only 4.5 inches high and the effects of heavy overgrazing the preceding year were apparent. On July 1 the average yield of 10 quadrats at each of the respective stations was 207, 266, and 235 gm. per square meter. At Burlington the leaves of wheat-grass had reached an average height of 16 inches and the flower-stalks of 26 inches at this time, at Phillipsburg the respective values were 22 and 30 inches, and at Lincoln 24 and 32 inches. The average yield of 10 quadrats from each station was 400, 457, and 606 gm. respectively.

Table 52.—*Growth and yield of crop-quadrats in 1921.*

Crop and station.	Average height.	Average number stalks per sq. meter.	Average number stalks per plant.	Average length heads or panicles in inches.	Average number heads per sq. meter.	Average total weight dry matter per sq. meter.	Maximum depth.
Oats:	*feet.*					*gm.*	*feet.*
Lincoln.......	3.2	375	3.3	10.5	283	792	4.8
Phillipsburg...	2.8	353	2.9	9	269	366	5.3
Burlington....	1.5	414	2.5	5	171	180	2.5
Wheat:							
Lincoln.......	3.2	648	2.8	4	365	557	4.3
Phillipsburg...	2.6	475	1.8	3.5	211	314	4.5
Burlington....	1.6	419	1.6	2.5	277	172	2.5
Barley:							
Lincoln.......	3.1	384	3.7	3.5	306	622	4.6
Phillipsburg...	2.8	253	2.2	3.25	201	369	6.0
Burlington....	1.3	255	1.6	2	197	122	2.5

On August 17, 12 quadrats cut in the high prairie at Lincoln yielded an average of 581 gm., and a similar number from the low prairie 929 gm., giving an average yield of 755 gm. This considerably exceeded the average weight of 11 tall-grass quadrats cut on August 30 at Phillipsburg, which was 477 gm. The average of the 44 quadrats from both cuttings at each station was as follows: Burlington 353 gm., Phillipsburg 402 gm., and Lincoln 603 gm. per square meter.

Crops of the smaller cereals were again grown in 1921 under conditions similar to those already described for 1920.

There was a regular decrease in height of the crop from the more humid to the more arid stations. The same general relation holds for the average number of stalks per square meter, except at Burlington, where many tiny stalks only 2 to 4 inches tall started growth relatively early and soon dried out, but remained until harvest. During 1920 the average number of stalks per square meter at Burlington was from one-third to one-half less than at the other stations, although the number at Phillipsburg often exceeded that at Lincoln. The average number of stalks per plant (1921) was in direct relation to the water-content of soil and other factors favorable or unfavorable to plant growth. In general, this relation held also during 1920. The average number

of heads per square meter and the average length of heads or panicles decreased from Lincoln to Phillipsburg to Burlington respectively. An exception to this occurred in the case of the number of heads of wheat at Burlington when compared with Phillipsburg, while the difference in this respect in the case of barley was small. However, a clear gradation in the reduction of total dry weight from east to west is apparent, giving a direct correlation with differences in water-content and humidity.

Results for 1922.

A single series of cut quadrats was obtained in 1922; these were taken on August 4 to 15, beginning with the short-grass plains. A series of 7 quadrats of *Bulbilis* at Burlington yielded an average of 179 gm., while the average of a similar series at Phillipsburg was 260 gm. A series of mixed short and tall grass cuttings at these two stations yielded 263 and 365 gm. respectively. The differences in the height-growth of foliage and flower-stalks for both kinds of grasses were again like those recorded for the preceding years. A series of 8 representative quadrats of wheat-grass was also obtained at both Phillipsburg and Lincoln. The average height of the foliage and flower-stalks respectively was 15 and 26 inches at the former station, and 17 and 30 inches at the latter. The respective yields were 334 and 541 gm. per square meter. A series of 27 quadrats containing mixed tall-grasses, largely *Andropogon scoparius*, *A. furcatus*, and *A. nutans*, was secured from these two stations. Repeated measurements showed that the average height of the general level of the foliage was 3 to 8 inches greater at Lincoln (13 to 24 inches tall) than in the mixed prairie. The yield in grams per square meter was 287 and 413 at the two stations respectively. The average yield of all the quadrats for this year in the three grassland communities was 224, 311, and 447 gm. at Burlington, Phillipsburg, and Lincoln respectively.

Table 53.—*Growth and yield of crop-quadrats, 1923.*

Crop and station.	Date of harvest.	Height.	Dry weight.[1]
Oats:		*in.*	*gm.*
Lincoln.......	July 7	42	2,637.0
Phillipsburg...	July 3	32	905.0
Burlington....	July 7	18	806.5
Wheat:			
Lincoln.......	July 7	42	2,395.0
Phillipsburg...	July 3	29	1,296.0
Burlington....	July 7	24	801.5
Barley:			
Lincoln.......	July 2	43	1,671.5
Phillipsburg...	July 3	37	1,292.5
Burlington....	July 7	26	1,038.5

[1] Total of straw and grain.

Five fields of maize were selected as representative of conditions about each of the three stations respectively, all of which were within a radius of 2 miles of the stations at which holard and other factor determinations were made. 10 stalks were then selected from various places in the field and the measurements recorded. The seventh leaf was selected for measurements of length and width. After completing the measurements on each stalk, the ear was husked

and placed in a sack, 10 ears being secured from each field. Finally, a typical stalk, as determined by the measurements of the 10 preceding, was selected, cut off at the ground line, cut into pieces, and after removing the ear but not the husks, was placed in another sack. These sacks were kept well ventilated, and after all had become thoroughly air-dried the weight of their contents was ascertained. Consistent and marked increases in height and diameter of stalk, height of ear, number and length of leaves, length and diameter of ear, as well as dry weight of stalks and ears, were found proceeding from west to east. The respective values for average weight of stalk and weight of ear were 320 and 82 gm. for Burlington, 413 and 110 gm. for Phillipsburg, and 496 and 183 gm. for Lincoln.

Results for 1923.

No clip-quadrats were taken from native vegetation in 1923, but three were made in plats of each of the grains at the three stations.

As in previous years, there was a pronounced decrease in the height of all three species from Lincoln westward, the plants at Burlington averaging about half as tall as at Lincoln. With respect to weight, the differences were even greater, oats and wheat yielding a third as much as at Lincoln. The average production for the three crops was 2,234 gm. at Lincoln, 1,164 gm. at Phillipsburg, and 882 gm. at Burlington, in close correspondence with rainfall, evaporation, and chresard.

Table 54.—*Average yield of clip-quadrats in grams.*

Dominant type of vegetation.	1920.			1921.			1922.		
	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.	Lincoln.	Phillipsburg.	Burlington.
Buffalo-grass	...	290	98	235	266	207	...	260	179
Wheat-grass	...	541	500	606	457	400	541	334	...
Mixed short and tall grasses	...	313	197	...	...	...	...	365	263
Mixed tall-grasses	458	410	...	755	477	...	413	287	...
Average (based on number of quadrats)	458	378	183	603	402	353	447	311	224

Summary.

In every case each grass or mixture of grasses yielded progressively less as the rainfall and holard decreased to the westward. The only exception is the case of buffalo-grass at Lincoln in 1921, and this has already been explained as an effect of grazing. Moreover, the averages for each year at the several stations show a graduated series, plant production increasing with increased efficiency of rainfall. However, it may be readily seen that the total yield at all of the stations was greater in 1921 than during the preceding or following year, an increase particularly noticeable in the case of the late-maturing tall-grasses.

It was early determined that the water relations of soil and air were controlling, other factors being merely contributory. The yield of pure stands of

short-grasses (*Bulbilis dactyloides* and *Bouteloua gracilis*), wheat-grass (*Agropyrum glaucum*), mixed short and tall grasses, and mixed tall-grasses was found to decrease from the true prairie to short-grass plains directly with the chresard and inversely with evaporation. The same relation was determined not only for the smaller cereals (oats, wheat, and barley), but also for alfalfa and sweet clover, as well as for maize. The plant yield at each station during different seasons was closely correlated with the variations in rainfall and holard. Deficiencies in water-content were naturally most marked late in the summer, and their effect was especially to be found in the late-maturing tall-grasses at the eastern stations. The results obtained with crop-plants were comparable in practically every respect, demonstrating that the method was equally applicable to both native and cultivated species.

Structural Response of Dominants and Subdominants.

Scope and Significance.

Comprehensive studies have been made of the leaf-structure of the great majority of the climax dominants of the grassland, as well as of a considerable number of seral dominants, subdominants, and trees. The material was obtained from both native and experimental plants, and in the case of the most important species represented the whole range of adjustment and adaptation, from salt-flat and swamp through low and high prairie to gravel-knoll at Lincoln, and from Nebraska City to Lincoln, Phillipsburg, Burlington, and Colorado Springs. As was to be expected, the grasses in general were very stable as to leaf-structure, the adjustment to the several climates occurring chiefly in function and growth, and hence in form. As a rule, distinct ecads were produced only in the series of edaphic stations with their more efficient differences, and the various species and genera naturally responded in very different degree even to these. Moreover, the effect of a particular habitat tended to be cumulative, and greater changes will probably appear in the course of the next few years. This is suggested by the existing adaptations shown by the leaves to the respective climates and recorded in the growth-forms and in the genera. With occasional exceptions, the leaf-structure is essentially the same for the dominants of each association, but differs markedly from one association to another. This seems to be a more recent adaptation that has been impressed upon the earlier one characteristic of each genus, with the consequence that it is necessary to distinguish three successive changes of varying degree in many dominants. Furthermore, this adaptational series affords a new approach to climatic shifts in the past and to the basic correlation of ungulate teeth and hoofs with changing vegetation. For these reasons, as well as because of the large amount of material available, it has seemed desirable to treat this phase of the investigation in a separate paper (Clements, 1924).

6. RÉSUMÉ.

PLAN AND METHODS.

An endeavor has been made to determine experimentally the factors operating in the composition and sequence of the climax grassland associations lying between the Missouri River and the Rocky Mountains. Lincoln, Nebraska, was selected as representative of true prairie, Phillipsburg, in north-central Kansas, of mixed prairie, and Burlington, in eastern Colorado, of short-grass plains. The altitude rises from 1,100 feet at Lincoln to 1,900 feet at Phillipsburg and 4,160 feet at Burlington. Since the associations are zoned from east to west, precipitation is the chief factor in determining the type of grassland; it decreases through this series of stations from 28 through 23 to 17 inches annual mean. A fourth station was maintained in the edge of the subclimax prairie at Nebraska City, 50 miles southeast of Lincoln, where the precipitation is 33 inches. In addition to these climatic stations, a series of edaphic ones ranging through gravel-knoll, high prairie, low prairie, salt-flat, swamp, and cultivated field was maintained at Lincoln. Moreover, some reciprocal transplants from Colorado Springs, Colorado; Tucson, Arizona; and Berkeley, California, were made at several of these stations.

Continuous records of the most important ecological factors, viz, precipitation, temperature of air and soil, humidity, and evaporation, were secured and frequent measurements were made of the holard to a depth of 4 feet, of light, and wind velocity, in addition to physical and chemical analyses of the soils. In the endeavor to interpret the various climatic and edaphic complexes in terms of plant activities, seeding and transplanting were carried out in different ways in the several communities. Seeds were sown in the undisturbed grass cover, others were placed in especially prepared trenches, while still others were sown in denuded quadrats. Seedlings were transplanted and reestablished under favorable conditions, and finally, large blocks of sod of mature plants were also employed. Some individuals were favored by watering, while others were exposed unaided to the test of the new habitat. Frequent checks were applied, resulting in complete records of the plant's activities. The investigation was begun in 1919 and continued until the close of the growing-season in 1923.

Fruits and seeds of a large variety of native grasses, forbs, shrubs, and trees from a wide range of habitats were employed. These were kept dry, but subjected to winter temperatures at Lincoln, Nebraska, and the germinability of the seeds was determined previous to planting, more than 60 species being tested. Great variability in the vitality of the seeds from year to year was found, and this could be traced to differences in climate. A germination of 20 to 25 per cent was exceptional, while one of 10 to 15 per cent was quite usual. Experiments were also made to disclose the effect of depth of planting upon germination and establishment. With most grasses a depth exceeding 0.5 to 1 inch was detrimental, and most species, like the composites, did best at a depth of 0.12 to 0.25 inch.

Surface sowing consisted of scattering the seeds in selected marked areas with a typical cover of vegetation, without disturbing the surface, and adding only enough débris to prevent the seeds from blowing away. Upon germination the seedlings at once met the keen competition from the existing vegeta-

tion for water and nutrients below ground and for light above. Frequently the latter was as low as 5 to 10 per cent, even early in the summer. By planting the seeds in a trench 4 inches deep, for which the sod had been broken, the soil pulverized, and a good seed-bed prepared, competition both above and below ground was removed for a short time. Denuded quadrats 0.5 meter square were also employed, the native vegetation likewise being removed and a good seed-bed prepared to a depth of 4 inches. This method eliminated competition for light and also for water and nutrients for a time, but other unfavorable factors were introduced, such as higher temperatures and greater evaporation. To tide the plant over the most critical period in its life, that of ecesis, the method of seedling transplants was also employed. These were grown in 2.5 to 4 inch flower pots until they were 3 or 4 weeks old, when they were transplanted into a specially prepared trench without disturbing the root system and watered for a period of about 10 days. A fourth method, that of transplanting mature perennials, was also utilized. Blocks of sod 10 inches square and 8 inches deep were transplanted reciprocally among most of the stations, a control block being replanted in the area where the species was secured. As far as possible, sowing and transplanting were done preceding or coincident with the inception of new growth and at a time when the holard was distinctly favorable.

COMMUNITIES.

The vegetation at each station has been studied and described in detail, in connection with the measurement of physical factors. Ninety per cent of the cover at Burlington (*Bouteloua-Bulbilis* association) consists of closed mats of short-grasses (mostly *Bulbilis*) forming a carpet seldom over 4 inches deep. At Phillipsburg (*Bouteloua-Stipa* association) tall-grasses, chiefly *Andropogon*, alternate with or form a layer above the shorter buffalo and grama grasses, the former reaching a height-level of 14 inches by midsummer. In the true prairie (*Stipa-Koeleria* association) the vegetation is distinctly of the tall-grass sod type. The chief genera are *Stipa*, *Koeleria*, *Andropogon*, and *Sporobolus*, with which are associated subdominants to form extensive societies. By June 1 the grasses have a height-level of 6 or 8 inches and the upper story of forbs attains a height of 15 to 22 inches. The subclimax prairie at Nebraska City (*Andropogon* associes), in addition to the true-prairie species which grow somewhat more rank, is characterized by the regular occurrence of *Andropogon furcatus* and *Panicum virgatum* on highland, while the various potential scrub societies usually held in check by mowing and fire, indicate its true relationship to forest. The low prairie at Lincoln is dominated, almost to the exclusion of other species, by *Andropogon furcatus* and *nutans*, *Panicum virgatum*, and *Spartina cynosuroides*, and is actually an edaphic postclimax (Plant Succession, 109), closely resembling the subclimax grassland. The swamp area is covered by the *Spartina* consocies bordered by a zone of *Poa pratensis*, but the bluegrass has been replaced by *Spartina* during the course of the experiment. The vegetation both here and in low prairie reaches a height of 4 or 5 feet. The salt-flat, on an area near the low prairie, had just enough sodium chloride, combined with an unfavorable soil structure, to exclude most prairie species, and is occupied by an open growth of *Distichlis spicata* and dwarf *Agropyrum glaucum*, seldom exceeding 5 to 8 inches

in height. The gravel-knoll is covered with mats of *Bouteloua gracilis* intermixed with *Bouteloua hirsuta* and often also with sparse tall-grasses in the intervals. These grow in porous sandy to gravelly drift soil, which forms the crest of a steep slope to the south. It is a miniature short-grass area of edaphic nature surrounded by true prairie.

PHYSICAL FACTORS FOR 1920.

A comparison of the physical factors during 1920 at the three major climatic stations shows that conditions for plant-growth in respect to rainfall, holard, temperature, humidity, wind, and evaporation were most favorable at Lincoln, intermediate at Phillipsburg, and least favorable at Burlington. These conditions are indicated by the native vegetation and are borne out by results of these experiments. Holard and humidity were found to be the controlling factors in plant growth, all others being secondary. The precipitation is not only 5 inches less at Phillipsburg and 11 inches less at Burlington than at Lincoln, but, owing to lighter showers, greater run-off, and increased evaporation, it is also progressively less efficient westward. While at Lincoln sufficient chresard was found at all times and at all depths to 4 feet for good growth, a period of midsummer drought occurred at Phillipsburg, and at Burlington the holard was favorable only until June (to a depth of 2 feet only), after which marked deficiencies were of frequent occurrence. Evaporation was lowest at Lincoln (9 to 25 c. c. daily), intermediate at Phillipsburg (11 to 32 c. c.), and highest at Burlington (23 to 60 c. c.).

ECESIS DURING 1920.

Both germination and establishment at the three stations were in the sequence of increasing water-content. Germination by all methods of planting averaged 86, 80, and 38 per cent, and establishment 42, 33, and 25 per cent at Lincoln, Phillipsburg, and Burlington respectively. Surface sowing gave both the poorest germination and poorest establishment, and seeding in denuded quadrats the best. In most cases better growth occurred at Lincoln than at the other two stations. Germination and growth in cultivated areas adjoining the several grassland stations were much better than in the sodded areas, but the sequence of the stations was the same.

In order to more fully understand the causes for the success or failure of seedlings, the root habit was studied both in native grassland and in cultivated soil. During 1918, when seedling *Bouteloua hirsuta*, *Andropogon scoparius*, *furcatus*, and *nutans*, and *Sporobolus asper* had reached heights of 6 to 10 inches in the grassland at Lincoln, the bulk of the root systems was found to occur at no greater depths than 8 to 18 inches. In cultivated areas seedlings of *Bouteloua*, *Sporobolus*, and *Liatris*, for example, reached heights of 3 or 4 inches in 44 days and the roots reached depths of 7 to 11 inches. By midsummer they were 8 to 18 inches tall, and the root depth 20 to 33 inches. The excellent growth made by all the species when properly spaced in fertile, cultivated soil with adequate holard emphasizes the keen competition prevailing in stabilized grassland. In the natural cover, as well as in the trench and denuded quadrat, most of the grasses require 2 or more years to produce seed, but under the former environment 73 per cent bore seed the first season. Because of the lack of root competition encountered by plants in the prairie,

the species in cultivated soil not only suffered less from drought, but also made a greater growth and tillered more heavily. For example, *Andropogon nutans* was 7 to 10 inches tall at the end of the first season in the true-prairie quadrats and 12 to 17 inches in the adjacent cultivated field. The tap-root of *Gleditsia* reached a depth of 40 inches by midsummer and that of *Onagra* 44 inches at the end of the first season, while *Andropogon scoparius* had a maximum lateral spread of nearly 1.5 feet, was rooted abundantly to 26 inches depth, and had a maximum penetration of 4 feet. These are typical examples of many findings. In the deep, mellow loess soil at Peru, Nebraska, the root penetration of seedlings was even greater. Of the 40 blocks of sod (9 species) transplanted at Burlington no species died, but only 53 per cent (unwatered sods) had flower-stalks, as compared with 70 per cent at Lincoln, where none of the 13 transplanted species died (23 blocks).

In the edaphic series, the low prairie exhibited a chresard 5 to 10 per cent greater than that of high prairie, and it also exceeded that at Nebraska City, where unusually dry weather prevailed. However, the humidity was higher at Nebraska City and the evaporation correspondingly less than on low prairie, which was more mesophytic than high prairie. The holard on the gravel-knoll and at Burlington was not very different, frequently falling to the hygroscopic coefficient, the short-grasses on both areas drying and turning brown late in July or in August. The average germination was highest at Nebraska City (93 per cent), intermediate on low prairie (77; 86 per cent on high prairie), and least on the gravel-knoll (71 per cent). The average of establishment was greatest in the cultivated area at Lincoln (100 per cent), 75 per cent on low prairie, 70 per cent at Nebraska City, and only 15 per cent on the gravel-knoll. Thus, all stations except the last exceeded high prairie (42), while Burlington with 25 per cent exceeded the gravel-knoll.

As to sod transplants on the gravel-knoll, all showed repeated rolling and drying back of the leaves; only a few flowered, and these did so earlier than elsewhere. On low prairie all grew well and blossomed. The transplants suffered from drought in the salt-flats, exhibiting wilting and yellowing of the leaves and dwarfed stature. Seven species, mostly from upland, succumbed to insufficient aeration in the swamp, and four in the *Poa* zone. All survived at Colorado Springs, where they were transplanted late, but none made a good growth. In the case of *Spartina cynosuroides* transplanted from swamp to high prairie two years earlier, many leaves reached a height of 40 inches and the roots were abundant to 9 or 10 feet depth, being much more branched than in lowland. *Panicum virgatum* showed a similar growth.

PHYSICAL FACTORS FOR 1921.

The season of 1921 was very favorable for growth, no marked drought periods occurring at Lincoln, where at least 5 and usually 8 or 10 per cent of chresard existed at all times and at all depths to 4 feet. At Phillipsburg the echard was approached once in July and twice in August, no water being available to a depth of 4 feet in late summer. As usual conditions were much worse at Burlington. At no time was water available in the third or fourth foot of soil, while after June 30 it was depleted repeatedly above the hard-pan at a depth of 2 feet. The humidity was highest at Lincoln and lowest at Burlington, where it often dropped to 10 or 20 per cent in the late afternoon.

Evaporation increased inversely with humidity and soil moisture, ranging from 8 to 27 c. c. daily at Lincoln, 8 to 43 c. c. at Phillipsburg, and 18 to 62 c. c. at Burlington. The remaining conditions for plant growth were also most favorable at Lincoln, intermediate at Phillipsburg, and poorest at Burlington.

ECESIS DURING 1921.

The germination results agreed with those of preceding years, Lincoln being highest (81 per cent), Phillipsburg second (68 per cent), and Burlington last (43 per cent). However, owing to the unusually favorable rainfall following germination at Phillipsburg, establishment was highest here (65 per cent), intermediate at Lincoln (40 per cent), and least at Burlington (7 per cent). No seedling transplants survived at Burlington, but 54 per cent lived at Lincoln, and 75 per cent at Phillipsburg. Although the surface-sown seeds germinated better than those in the trench, establishment, as in 1920, was least on the surface, next in the trench, and best in denuded quadrats, the latter exceeding that of seedling transplants. As to the 1920 plantings, the average survival during 1921 was greatest at Lincoln and least at Burlington. An examination of the grasses and forbs during the second year in the quadrats at Phillipsburg showed that they were well established, the roots penetrating to depths of 2.5 to 4 feet.

Sods on the high prairie all did well, but 4 species died at Burlington, and the rest, including those that had been repeatedly watered, were represented by mere remnants of the original fine blocks. Of those transplanted to high prairie in 1920, all survived and some increased their area, but at Burlington 1 died, while all suffered from drought and were considerably dwarfed. By midsummer of the second season's growth in the short-grass plains, the roots were confined to the surface 2 to 2.5 feet, except in the watered area, where they penetrated 5 to 7 feet.

As to the other stations, the season at Nebraska City was one of drought, though the soil usually had a 10 per cent chresard at all depths to 4 feet. This exceeded the water-content on low prairie, where the chresard in the surface 6 inches was nearly exhausted in June. Conditions on the gravel-knoll were more favorable than during 1920. Evaporation at Nebraska City and low prairie was lower than on the high prairie and was highest on the gravel-knoll. The average germination at the three stations was very similar (63 to 76 per cent) and in all cases less than on high prairie (81 per cent). The rate of establishment was in the following order: Nebraska City 41 per cent, high prairie 40 per cent, low prairie 38 per cent, and gravel-knoll 29 per cent, the last considerably exceeding Burlington (7 per cent). Seedling transplants gave the best growth on low prairie (92 per cent), next at Nebraska City (57 per cent), then high prairie (54 per cent), and least in gravel-knoll (14 per cent). Four species of sod transplants died on the gravel-knoll, and three were shaded out in low prairie, while all survived on the salt-flat and in the swamp, the latter being much drier than in 1920. Of the 1920 transplants, no species died on the gravel-knoll, one succumbed to the shade in low prairie, one died on the salt-flat, and 6 in the swamp and bluegrass zone.

PHYSICAL FACTORS FOR 1922.

The season of 1922 was fairly favorable for growth, except for the latter part, when severe drought occurred at all the stations, though it was relatively

less marked on the Great Plains. A margin of at least 5 per cent and more, usually 7 to 11 per cent, chresard existed at all times to a depth of 4 feet in the high prairie at Lincoln, while at the mixed-prairie station drought began late in June and continued throughout the season. There was often no chresard to a depth of 4 feet. The soil in spring and early summer was as usual quite moist at Burlington, but deficiencies were marked and practically continuous after the middle of June. As usual, the factors were most favorable in true prairie and least so on the Great Plains.

ECESIS DURING 1922.

As for the two years preceding, the average germination under all methods of planting was highest at Lincoln (74 per cent), intermediate at Phillipsburg (63 per cent), and least at Burlington (44 per cent). In surface sowing Phillipsburg slightly outranked Lincoln, due to differences in soil structure. This also accounts for the greater survival of seedling transplants at the former, the percentages being 78, 70, and 26 respectively. Establishment was decidedly highest in true prairie, viz, 62 per cent; it was but 39 per cent in mixed prairie, and 26 per cent in the short-grass plains. Germination averaged best on the surface, next in denuded quadrats, and least in the trench, but establishment was in the following order: denuded quadrats, trench, and surface, the last giving the lowest percentage. *Bouteloua gracilis* made the best growth in the quadrats at Burlington and the least at Lincoln, but for all of the other species the growth-rate was in the sequence of increasing water-content, i. e., eastward. *Andropogon nutans*, *Kuhnia glutinosa*, *Bouteloua racemosa*, and *Panicum virgatum* were 4 to 12 inches tall at Lincoln, 3 to 9 inches at Phillipsburg, and 1 to 5 inches at Burlington.

The survival for the 1920 surface-sowings was 33 per cent at Burlington only; for the trench it was 33 per cent at Lincoln and Phillipsburg, and for the quadrats 55 per cent at Lincoln and 43 per cent at Burlington, the plants at Phillipsburg having been mostly excavated for root study. The average survival of 1921 plantings and seedling transplants was greatest at Phillipsburg and lowest at Burlington. Two species died out of the 26 transplanted to high prairie in 1922; these were both dicotyls with strong taproots. All of the 13 species of grasses transplanted to Burlington survived, although they flowered less than at Lincoln and nearly all were dwarfed. Of the 1920 sod transplants, 2 died on high prairie during 1922, but only 1 at Burlington, although many more individuals out of the 40 transplanted blocks of sod succumbed here. None of the 1921 transplants died on the high prairie; several increased their territory, and 12 of the 16 species blossomed. At Burlington several individuals died, but only 1 species vanished entirely. *Agropyrum spicatum* and *Bouteloua racemosa* were the sole survivors of the unwatered lot.

As to the other stations, the season at Nebraska City was one marked by drought in June and August. However, the soil usually had a chresard of 8 per cent below the first foot, but that in the surface foot, which most critically affects seedlings, was practically exhausted two or three times during the summer, being less favorable than in 1921. Conditions as to the holard were more favorable on low prairie, where a considerable excess prevailed over that on high prairie. On the gravel-knoll the grama grasses dried during the

drought, as no moisture was available in the first 2 feet of soil. The germination of surface-sown seed was not greatly different at the three stations (70 to 84 per cent), this method of sowing giving the best germination. The average germination was 67 per cent at Nebraska City, 75 on low and 74 on high prairie. Establishment gave the usual sequence with respect to method of planting. It averaged 46 per cent at Nebraska City, 62 per cent on high prairie, and only 50 per cent on the more densely shaded low prairie, where light values ranged from 2 to 10 per cent. Seedlings did best on high prairie (70 per cent) where they were watered, next at Nebraska City (59 per cent), and poorest on low prairie (45 per cent). Three of the sod transplants on low prairie succumbed to the dense shade, as did 4 in the swamp, while one died on the salt-flat. Of the 1920 sods, 3 died on the gravel-knoll, 4 were shaded out in low prairie, and 1 died in the salt-flat, but no further mortality occurred in the rapidly drying swamp. Of the 1921 transplants, 3 more died on the gravel-knoll, 5 in low prairie, 1 in the salt-flat, and 2 in the swamp.

BEHAVIOR DURING 1923.

In 1923, a season with high spring and summer rainfall at the western stations, the plants made an excellent growth. Not only was the rainfall above the normal, but the rains were also well distributed, drought periods being fewer and shorter than usual. At Lincoln the precipitation for spring and summer averaged below normal. The preceding fall and winter had been one of unusually severe drought, and high losses were sustained at all the stations. In the major climatic stations these were greatest at Burlington, intermediate at Phillipsburg, and least at Lincoln. For example, losses of the 1921 plantings and transplants were 43, 28, and 13 per cent in the above sequence of stations. The mortality at all stations averaged greatest for the plants of a single year's establishment, next for those 2 years old, and least for those established for 3 seasons, e. g., the respective losses at Burlington being 85, 43, and 16 per cent. The survival was greatest in denuded quadrats, this method even outranking that of transplanting blocks of sod.

In the survival of surface-sown plants for all years Phillipsburg ranked first (14 per cent), Burlington second (11 per cent), and Lincoln last (9 per cent). The average germination was respectively 79, 45, and 76 per cent, Lincoln taking second and Burlington third place. The average germination in trenches decreased from Lincoln westward, the percentages being 85, 59, and 21 respectively. The average survival for all years at the end of 1923 was in the same order, the percentages being 27, 21, and 0 respectively. Germination in denuded quadrats was greatest at Lincoln for every year except one, and least at Burlington, with one exception, the percentages for the three stations being 81, 73, and 60. With a single exception, establishment was likewise in the same order, viz, 72 per cent in true prairie, 60 per cent in mixed prairie, and 43 per cent in the short-grass plains, and this was also true of survival at the end of 1923, the percentages being 44, 22, and 21 respectively. Hence, while surface-sowing ranked highest in germination, it resulted in the lowest estabishment.

Transplanted seedlings usually did best at Phillipsburg, the average survival at the end of 1923 being 44 per cent as compared with 37 per cent at Lincoln and 3 per cent at Burlington.

Permanent establishment by the end of 1923 under the three methods of planting was 44, 27, and 9 per cent respectively at Lincoln, 22, 21, and 14 per cent at Phillipsburg, and 21, 0, and 11 per cent at Burlington. This was always greatest in the denuded quadrats and next greatest in the trench.

The results of seeding and transplanting at Nebraska City and on low prairie are not greatly different, although often somewhat better than on high prairie, while ecesis on the gravel-knoll was often only slightly higher than that at Burlington. At the latter, as on the gravel-knoll, drought was the deciding factor, while on low prairie, as well as at Nebraska City, light played the dominant rôle.

Certain species were found to survive more frequently than others. Out of the total plantings at Nebraska City, Lincoln, Phillipsburg, and Burlington, beginning with 1920, *Andropogon nutans* survived in 35 different places by the end of 1923. The survival of other species was in the following order, the figures indicating the different number of places in which they survived: *Bouteloua gracilis* 18, *B. racemosa* 15, *B. hirsuta* 14, *Sporobolus asper* 11, *Aristida purpurea*, *Elymus canadensis*, and *Liatris punctata* 10 each, *Andropogon scoparius* 8, *A. furcatus* 7, *Petalostemon candidus* 6, *Stipa spartea*, *Desmodium canescens*, and *Liatris scariosa* 5 each, *Kuhnia glutinosa* 4, *Panicum virgatum*, *Stipa viridula*, *Symphoricarpus occidentalis* 3 each, *Gleditsia triacanthus*, *Symphoricarpus vulgaris*, *Koeleria cristata*, *Ratibida columnaris*, *Robinia pseudacacia*, and *Acer saccharinum* 2 each, and *Stipa comata*, *Agropyrum glaucum*, *Pinus ponderosa*, and *Acer negundo* each only 1.

As regards sod transplants, by the fall of 1923 over half of the 1920 plantings at Burlington had died. *Agropyrym glaucum* alone remained in the unwatered area. The 1921 transplants, half of which were watered, lost 15 out of 22 individuals, *Agropyrum* and *Bouteloua racemosa* alone surviving in the unwatered area, while practically all of the rest showed clearly that they would not last much longer. 83 per cent of the 1922 transplants were winter-killed, and at the end of the second season *Bouteloua gracilis* and remnants of 2 other species alone remained. These results clearly reveal the uncongenial nature of the Great Plains, in so far as prairie species are concerned.

Relatively few species died on the high prairie, even *Spartina cynosuroides* and *Panicum virgatum* forming seed. Of the 1920 plantings only 6 individuals had died, including 2 plants of *Distichlis spicata*, which never flourished out of its own saline habitat. Of the 1921 plantings a single one succumbed. Six forbs among the 1922 plantings died, and 1 lot of *Bouteloua gracilis*. Several of the species had considerably extended their area.

On the gravel-knoll the mortality was much greater, although here likewise several low-prairie species became permanently established, their roots extending well into the clay subsoil below 4 feet. Three species of the 1920 and 7 of the 1921 lot succumbed, but others planted in 1919 still survived, *Bulbilis* and *Agropyrum* being quite at home. Nearly all were somewhat dwarfed, and they began growth and matured earlier than at the other Lincoln stations.

Exceedingly interesting results were obtained on low prairie. Of the 14 species and 28 blocks of sods transplanted in 1920, all flourished, including *Bulbilis* and *Bouteloua gracilis*. By the second season, however, 1 species was shaded out, 4 the next, and 1 in 1923, so that by the end of the fourth summer the dominants of the low prairie alone, viz, *Andropogon nutans* and *furcatus*,

Panicum virgatum, Elymus canadensis, and *Spartina cynosuroides* were flourishing, *Stipa,* a single *Koeleria,* and *Andropogon scoparius* surviving from the high prairie. Of the 1921 transplants, 5 subclimax dominants developed normally, but of the 10 species remaining all had succumbed but 3 represented by mere remnants. Two or three years were sufficient for the tall-grasses to overshade and cause *Bulbilis* and *Bouteloua gracilis* and *hirsuta* to disappear. This applies also to several true-prairie dominants. Of the 1922 transplants a total of 11 species had succumbed by the end of 1923, the process of elimination being well under way.

On the salt-flats, while the plants were able in most cases to tolerate conditions (only 6 species among the three years' plantings succumbing), they made a very poor growth, did not extend their territory, and seeded very poorly. For the most part they had a paler color and in every way reflected the unfavorable environment, except the indigenous *Distichlis* alone.

Transplants in the swamp lost heavily, at first from poor aeration and later from lack of light, after a dam was built above the experimental area and the swamp dried out. High-prairie species were most affected and died in greatest numbers, the flower-stalk often rotting off at the surface of the saturated soil. By 1923, *Spartina, Panicum virgatum,* and *Elymus canadensis,* all of which grew well, were the only survivors among the 13 species planted in the swamp, while these and *Poa pratensis* were the 4 survivors of a similar lot in the *Poa* zone, which was now overgrown with *Spartina.*

During the course of the experiment it was found that species of widely different families exhibit the phenomenon of dormancy, the seeds lying in the soil for one or more years before germinating. Among the most conspicuous cases the following may be enumerated: *Robinia pseudacacia, Gleditsia triacanthus, Petalostemon candidus,* and *Lespedeza capitata* among legumes; *Sporobolus asper, Andropogon nutans, Panicum virgatum,* and *Andropogon furcatus* among grasses; and likewise *Kuhnia glutinosa, Corylus americana,* and *Acer negundo.* While the volunteer growth of these plants during the second or third year has not been recorded in detail, because of the risk of confusion, it may be stated that in general they suffered the same fate as the original plantings.

BEHAVIOR OF TREES AND SHRUBS.

The fate of trees and shrubs planted or transplanted by rhizomes into grassland is of especial interest. The trees employed were *Acer negundo, A. saccharinum, Gleditsia triacanthus, Robinia pseudacacia,* and *Pinus ponderosa,* together with the following shrubs: *Corylus americana, Symphoricarpus occidentalis,* and *S. vulgaris.* At Burlington none survived longer than the first season, and at Phillipsburg the only survivors at the end of 1923 were the 2 species of *Symphoricarpus* planted in 1921. *Corylus* (delayed growth), *Robinia, Gleditsia,* and *Acer saccharinum* of the 1922 planting, and *Robinia* of 1921 survived on high prairie. On low prairie *Symphoricarpus occidentalis* of the 1921 planting and *Acer saccharinum* of 1922 alone survived. None lived on the gravel-knoll, but at Nebraska City both species of *Symphoricarpus* of 1921 and *Acer negundo* and *Pinus ponderosa* of 1922 were alive at the end of the summer of 1923. However, as shown by a series of earlier experiments with trees at Lincoln, the results of which are as yet unpublished, the possibility of

tree-growth in stabilized grassland is almost nil, since tree seedlings are killed by drought on upland and are shaded out on lowland.

GERMINATION AND SURVIVAL AT THE CLIMATIC STATIONS.

The percentage of germination for each year and for each method and the percentage of survival for the first year of planting as well as succeeding years are given in table 55. The percentage of germination under surface sowing was greatest at Lincoln during 1920, and at Phillipsburg during 1921 and 1922, while it was least at Burlington for all three years. The averages for the three years are Phillipsburg 79 per cent, Lincoln 76 per cent, and Burlington 45 per cent (table 56). In regard to establishment, Burlington ranked first in 1920 (clearly an erratic case), Phillipsburg in 1921, and Lincoln in 1922. As to the survival of plants of all years, at the end of 1923 Phillipsburg was first with 14 per cent, Burlington second, 11 per cent, and Lincoln third, 9 per cent. The greater germination and establishment at Phillipsburg were probably due to the structure of the soil (p. 12).

Germination in the trenches was highest at Phillipsburg in 1920, but at Lincoln for the other years, Burlington coming last. The average germination for the three seasons was greatest at Lincoln (85 per cent), next at Phillipsburg (59 per cent), and lowest at Burlington (21 per cent). Survival in 1920 and for 1923 was greatest at Lincoln, but in 1921 greatest at Phillipsburg, Burlington regularly ranking third. However, in the survival for all plantings at the end of 1923, the sequence is Lincoln, Phillipsburg, and Burlington, with respective percentages of 27, 21, and 0.

Germination in the denuded quadrats was greatest at Lincoln during 1920 and 1922, and least at Burlington, except in 1921, when it exceeded Phillipsburg and Lincoln. The average germination for the three years at the several stations was 81, 73, and 60 per cent, in the order of decreasing rainfall. Establishment was also greatest at Lincoln every year and least at Burlington, except during 1922, when the latter exceeded that at Phillipsburg. The average establishment for the three years was 72 per cent in the true prairie, 60 per cent in mixed prairie, and 43 per cent in the short-grass plains. The percentage of survival for all plantings in quadrats for the three years was, in the above order, 44, 22, and 21.

Transplanted seedlings did best at Phillipsburg both during 1921 and 1922 and poorest at Burlington. Moreover, the average survival at the end of 1923 was greatest at Phillipsburg (44 per cent), next at Lincoln (36 per cent), and least at Burlington (3 per cent). The explanation of the better survival in the mixed prairie seems clearly to be sought in the more favorable soil structure.

With reference to the success of the various methods, surface sowing gave the poorest results as to germination in 1920, but the best the other two seasons, the quadrat ranking second (first in 1920), and the trench third. On the other hand, establishment was always greatest in the denuded quadrat, second in the trench, and least on the surface. The survival for all years at the end of 1923 was greatest in denuded quadrats, and least on the surface. At Lincoln under the three methods it was 44, 27, and 9 per cent, respectively, at Phillipsburg 22, 21, and 14 per cent, and at Burlington 21, 0, and 11 per cent. The seedling-transplant method was somewhat less successful than sowing in quadrats, but more satisfactory than sowing in trenches.

The persistence of plants is high after surviving a single growing-season, but the mortality is also usually greater during the second winter and summer than for any year afterward.

During the three years the average germination for all methods was greatest in true prairie (81 per cent), second in mixed prairie (70 per cent), and least at Burlington (42 per cent). The average establishment was, in the same sequence of stations, 48, 46, and 20 per cent, as was also the average survival at the end of 1923, viz, 27, 19, and 11 per cent. Thus, the experimental evidence clearly indicates that the best conditions for growth are to be found in true prairie and the least favorable ones in the short-grass plains, conditions in the mixed prairie being intermediate.

GERMINATION AND SURVIVAL AT THE EDAPHIC STATIONS.

Results from the series of edaphic stations show that the germination of surface-sown seeds was very similar in the low prairie and at Nebraska City during the three years, where it slightly exceeded that on the high prairie at Lincoln. The survival at the end of the first season averaged greater at both

TABLE 55.—*Per cent of germination and survival at all stations, 1920-1923.*

Station.	Surface sowing.					Trench sowing.				
	P. ct. germination.	P. ct. survival.				P. ct. germination.	P. ct. survival.			
		1920.	1921.	1922.	1923.		1920.	1921.	1922.	1923.
1920.										
Lincoln (high prairie)	66	0	..	..	..	92	45	42	33	33
Phillipsburg	50	0	..	..	..	100	33	33	33	33
Burlington	46	33	33	33	33	15	0	..	..	..
1921.										
Lincoln (high prairie)	79	..	9	(9)	(9)	92	..	45	36	36
Phillipsburg	100	..	83	50	25	43	..	50	33	17
Burlington	38	..	0	..	..	15	..	0	..	..
1922.										
Lincoln (high prairie)	82	..	..	50	17	70	..	..	63	13
Phillipsburg	86	..	..	42	16	35	..	..	25	13
Burlington	50	..	..	0	..	32	..	..	14	0
1920.										
Gravel-knoll (Lincoln)	..	..	..	..	..	71	30	0	..	..
Low prairie (Lincoln)	75	33	(17)	(17)	(17)	57	100	50	50	50
Nebraska City	80	50	38	(38)	(38)	100	60	30	20	20
1921.										
Gravel-knoll (Lincoln)	..	..	..	..	..	55	..	17	0	..
Low prairie (Lincoln)	78	..	14	0	0	75	..	17	Excavated for roots.	
Nebraska City	78	..	29	29	29	50	..	33	17	17
1922.										
Low prairie (Lincoln)	84	..	..	25	6	60	..	..	64	43
Nebraska City	70	..	..	50	21	62	..	..	33	15

TABLE 55.—*Per cent of germination and survival at all stations, 1920-1923*—Continued.

Station.	Denuded quadrats, sowing.					Seedling transplants, p. ct. survival.		
	P. ct. germination.	P. ct. survival.						
		1920.	1921.	1922.	1923.	1921.	1922.	1923.
1920.								
Lincoln (high prairie)	100	80	55	55	55	..	..	..
Phillipsburg	90	67	67	Excavated for roots.		..	..	..
Burlington	54	43	43	43	43	..	..	..
1921.								
Lincoln (high prairie)	71	..	65	30	30	54	39	23
Phillipsburg	61	..	63	31	31	75	58	50
Burlington	76	..	21	11	5	0	..	..
1922.								
Lincoln (high prairie)	71	..	..	72	48	..	70	50
Phillipsburg	69	..	..	50	36	..	78	37
Burlington	50	..	..	64	14	..	26	5
1920.								
Gravel-knoll (Lincoln)	71	0	..	..	..	..	..	..
Low prairie (Lincoln)	100	91	82	73	45	..	..	..
Nebraska City	100	100	90	80	70	..	..	..
1921.								
Gravel-knoll (Lincoln)	71	..	40	30	20	14	14	14
Low prairie (Lincoln)	75	..	83	42	25	92	69	31
Nebraska City	68	..	60	40	40	57	57	50
1922.								
Low prairie (Lincoln)	81	..	..	60	50	..	45	39
Nebraska City	69	..	..	54	36	..	59	45

NOTE: Numbers in parenthesis indicate that the plants had merged into the native sod and were not traced further.

stations (low prairie 24, Nebraska City 43 per cent) than on high prairie (20 per cent), while the average survival at the close of 1923 was respectively 8, 29, and 9 per cent.

The average germination in the trenches for all years was least on the gravel-knoll, 63 per cent; it reached 64 per cent in low prairie and 71 per cent at Nebraska City, as compared with 85 per cent on high prairie. However, ecesis on the gravel-knoll was less than half that on high prairie (23 in contrast to 51 per cent), while in low prairie and at Nebraska City it was 60 and 42 per cent respectively. The survival at the end of 1923 was nil on the gravel-knoll, 31 per cent in low prairie, and 17 per cent at Nebraska City, as compared with 27 per cent on high prairie.

Germination in denuded quadrats averaged 71, 85, and 79 per cent on gravel knoll, low prairie and Nebraska City respectively, in contrast to 81 per cent on high prairie. The corresponding percentages were 20, 78, and 71, as against 72 on high prairie, the survival at the end of 1923 being 10, 40, 49, and 44 per cent respectively.

The ecesis of seedling transplants was 14 per cent on the gravel-knoll (1921 only), 68 per cent in low prairie, and 58 per cent at Nebraska City, as compared with 62 per cent on high prairie. The respective survival at the end of 1923 was 14, 35, and 48 per cent, as against 36 per cent on high prairie. Thus,

TABLE 56.—*Summary of percentages of germination and survival.*

SURFACE SOWING.

Station.	Year of planting.	P. ct. germination.	Average.	Survival at end of first year.	Average.	Survival at end of 1923.	Average.
	1920	66		0		0	
Lincoln (high prairie)....	1921	79	76	9	20	9	9
	1922	82		50		17	
	1920	50		0		0	
Phillipsburg............	1921	100	79	83	42	25	14
	1922	86		42		16	
	1920	46		33		33	
Burlington.............	1921	38	45	0	11	0	11
	1922	50		0		0	
	1920	75		33		17	
Low prairie (Lincoln)....	1921	78	79	14	24	0	8
	1922	84		25		6	
	1920	80		50		38	
Nebraska City..........	1921	78	76	29	43	29	29
	1922	70		50		21	

TRENCH SOWING.

Station.	Year of planting.	P. ct. germination.	Average.	Survival at end of first year.	Average.	Survival at end of 1923.	Average.
	1920	92		45		33	
Lincoln (high prairie)....	1921	92	85	45	51	36	27
	1922	70		63		13	
	1920	100		33		33	
Phillipsburg............	1921	43	59	50	36	17	21
	1922	35		25		13	
	1920	15		0		0	
Burlington.............	1921	15	21	0	5	0	0
	1922	32		14		0	
Gravel-knoll (Lincoln)...	1920	71	63	30	23	0	0
	1921	55		17		0	
	1920	57		100		50	
Low prairie (Lincoln)....	1921	75	64	17	60	Excav.	31
	1922	60		64		43	
	1920	100		60		20	
Nebraska City..........	1921	50	71	33	42	17	17
	1922	62		33		15	

DENUDED QUADRATS.

Station.	Year of planting.	P. ct. germination.	Average.	Survival at end of first year.	Average.	Survival at end of 1923.	Average.
	1920	100		80		55	
Lincoln (high prairie)....	1921	71	81	65	72	30	44
	1922	71		72		48	
	1920	90		67		Excav.	
Phillipsburg............	1921	61	73	63	60	31	22
	1922	69		50		36	
	1920	54		43		43	
Burlington.............	1921	76	60	21	43	5	21
	1922	50		64		14	
Gravel-knoll (Lincoln)...	1920	71	71	0	20	0	10
	1921	71		40		20	
	1920	100		91		45	
Low prairie (Lincoln)....	1921	75	85	83	78	25	40
	1922	81		60		50	
	1920	100		100		70	
Nebraska City..........	1921	68	79	60	71	40	49
	1922	69		54		36	

TABLE 56.—*Summary of percentages of germination and survival*—Continued.

SEEDLING TRANSPLANTS.

Station.	Year of planting.	P. ct. germination.	Average.	Survival at end of first year.	Average.	Survival at end of 1923.	Average.
Lincoln (high prairie)....	1921	....	....	54	62	23	36
	1922	....	....	70		50	
Phillipsburg............	1921	....	....	75	77	50	44
	1922	....	....	78		37	
Burlington............	1921	....	....	0	13	0	3
	1922	....	....	26		5	
Gravel-knoll (Lincoln)...	1921	....	....	14	14	14	14
Low prairie (Lincoln)....	1921	....	....	92	68	31	35
	1922	....	....	45		39	
Nebraska City..........	1921	....	....	57	58	50	48
	1922	....	....	59		45	

no consistent differences are to be found between the low-prairie station at Lincoln, which is really a postclimax stage in the true-prairie climate, and the subclimax prairie at Nebraska City, both averaging somewhat better than the high-prairie station at Lincoln. The gravel-knoll station, climatically a preclimax to the true prairie, excelled Burlington in percentage of germination and establishment, but barely equaled it in survival at the end of 1923.

SURVIVAL OF SOD TRANSPLANTS.

While the number of species lost at Burlington from the 1920 transplanting was the same as that at Lincoln, the individual losses were far greater, owing to the transplanting of a larger number of blocks of each species at the plains station. The relative losses for 1921 were representative. Losses in individuals on the gravel-knoll were consistently high, while those on low prairie were similarly high, though the cause for the latter was not drought, but shade. The losses in the swamp were greatest during 1920, because of poor aeration due to an excessive amount of water, while later losses were caused almost entirely by the density of shade. While in general the high-prairie species were the ones to disappear from swamp and low prairie, no consistent loss of individual species occurred at the other stations. Excluding the losses of 1923, owing to the very dry fall and winter, the following species suffered total loss in as many instances as are indicated by the number: *Koeleria cristata* 14; *Andropogon scoparius* 7; *Elymus canadensis*, *Poa pratensis*, *Agropyrum glaucum*, and *Bouteloua racemosa* 6 each; *Distichlis spicata* 5; *Stipa spartea* and *Andropogon nutans* 4 each; *Bouteloua gracilis*, *Panicum virgatum*, *Andropogon furcatus* 3 each; and *Bouteloua hirsuta*, *Bulbilis dactyloides* and *Sporobolus asper* 1 or 2 each.

PHYTOMETRIC METHODS.

In spite of the abnormal weather during 1923, the investigation of the transpiration of standard plants and sod-cores of native and cultivated species, and of the growth of natural cover and crops, as shown by cut-quadrats, yielded results of value in confirmation of those obtained by the methods of experimental vegetation. This was especially true of the cut-quadrats, as

these also extended through a series of nearly normal years. They not only demonstrated the close dependence of grassland and crop communities upon rainfall and water-content, but also the intimate relationship of the various prairie climaxes and climates. The evidence drawn from germination, ecesis, function, and growth was corroborated in large measure by the adaptation shown in leaf-structure, though this was more or less obscured by the fixity of type in certain species.

Table 57.—*Summary of sod transplants.*

Station.	No. of species.	No. of trans-plants.	Loss of species (not individuals).			
			1920.	1921.	1922.	1923.
1920.						
Lincoln (high prairie)............	13	23	0	0	2	0
Burlington......................	9	40	0	1	1	0
Gravel-knoll....................	11	28	0	0	3	0
Low prairie.....................	14	28	0	1	4	1
Salt-flat........................	13	17	0	1	1	0
Swamp..........................	13	13	7	2	0	1
Poa zone in swamp..............	13	13	4	4	0	0
1921.			....			
Lincoln (high prairie)............	15	16	....	0	0	1
Burlington......................	11	22	....	4	1	3
Gravel-knoll....................	14	18	....	4	3	0
Low prairie.....................	15	16	....	3	5	1
Salt-flat........................	15	18	....	0	1	1
Swamp..........................	14	14	....	0	2	7
Poa zone in swamp..............	13	13	....	0	0	6
1922.			....	....		
Lincoln (high prairie)............	26	30	....	....	2	2
Burlington......................	13	18	....	....	0	10
Low prairie.....................	25	28	....	....	3	8
Salt-flat........................	14	14	....	....	1	1
Swamp..........................	14	16	....	....	4	6
				....		

ATTAINMENT OF OBJECTIVES.

The conclusion seems to be warranted that the general objective of developing the basic method of experimental vegetation so that it combines the maximum of demonstrability and objectivity has been achieved. While the methods involved require further refinement and testing, there can be little question that they are prerequisite to fundamental and permanent progress in the field of vegetation. The special objectives set have also been attained, though necessarily in varying degree, since such problems as those of the cycle and of competition will constantly unfold with advancing research. Both planting and factor results have confirmed the essential variety within unity that characterizes the grassland formation with its associations, and harmonize completely with the evidence from cyclic changes and relicts. They have further illuminated the relation of seral habitats and communities to those of the climax, and have likewise justified the concepts of subclimax, postclimax, and preclimax. The essentially subclimax nature of the low prairie has been corroborated, as have also the climatic and phylogenetic relationships of the subclimax prairie. The evaluation of competition as a controlling process in

grassland has been attended by unexpected success, especially in connection with the persistence of subclimax prairie in regions of forest climate. With respect to natural migration, the experimental evidence lends no support to the assumption that single or scattered individuals regularly invade climaxes with success, but on the contrary indicates that all such invasion is a mass movement in response to wet and dry phases of climatic cycles. The demonstration of the phyletic relationship between subclimax prairie, true prairie, mixed prairie, and short-grass areas and between the corresponding climates in the first three cases appears conclusive, and in conjunction with relict and cyclic results will constitute the basis for future research in the grassland formation.

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BEHAVIOR TABLES.

These have been selected from the complete record to illustrate the behavior in the different stations under various types of sowing and planting.

TABLE 58.—*Sowing in denuded quadrats, high prairie, Lincoln, Apr. 16 and May 4, 1920.*

Species.	1920.						
	May 15.	May 25.	June 2.	June 15.	July 15.	Aug. 9.	Aug. 30.
1. Andropogon nutans	Abund., 0.5–1″	Fair	Thick, 1–1.5″	Thick.	5–8″ tillering, 4–6 lvs.	5–7″, 3–5 lvs., half dead.	7–10″, good.
	1	Thick, 0 5″	Thriving, 1–1.5″	Thick, good	4–6″, 3–5 lvs	Tillering heavily, 4–6″, fine.	Good, thick.
2. Andropogon scoparius	Abund., 0.5″	Abund	Thick, 1″, thriving.	Good	3–4″, 5–6 lvs., 3–4 tillers.	5–8″, thick, 3–5 tillers.	5–10″, heavily tillered.
	1. None	Fair	Good, 0.5″	Good	2–4″, thick	5–8″, abund	Do.
3. Aristida purpurea	None	None	Very sparse, 2″	Only 2 left	9, 2–3″, bunchy	5″, tillering heavily, thriving.	3–5″, good clumps.
	1. None	Poor	Do	Thin	3–4″, good, well tillered.	6–8″, 5–6 lvs., good	6–8″, good bunches.
4. Bouteloua gracilis	Very few	Few	Few, thriving, 1–2″	Fine	Thriving	4–6″, well tillered, thriving.	4″, exc., heavily tillered.
5. Elymus canadensis	Germinated	Good	Thick, thriving, 2–3″.	Good	3.5–5″, fair	6–9″, tillering, fair	4–8″, good.
6. Koeleria cristata	Abund	Thick, doing poorly	0.5–1″, not abund	Very few left, poor	Dead.		
	1	0–5″, thick	Fair, 1″	Not over 0.5″	3–4″, tillering heavily	Dead.	
7. Stipa comata	Abund., 0.5–2″	1.5–2″, good	Fair, 2″, many	Good	Eaten back, 1–2″	Nearly all dead	Dead.
8. Stipa coronata	Abund., 2″	Many died at 2.5″	2–3″, nearly all dead.	Dead.			
9. Stipa eminens	Abund., 0.5–1″	1.5–2″, good	Thick, thriving, 2″	Fair	Many dead, eaten almost to ground.	Eaten to ground, nearly all dead.	Eaten, remnants only.
10. Stipa setigera	Abund. 2″	Many died at 2.5″	2–3″ thick, thriving	Thick, good	1–4″, fair	Fair, eaten back to 1–2″.	3″, 3–5 lvs., thick.
	1. Abund., 0.5–1″	0.5–2″, good	Do	Do	Fair	Eaten back to 2–3″, thriving.	2–4.5″, tillering, eaten back.
11. Stipa viridula	Abund., 2″	Good	Do	Good	3–5″, good, 3–4 lvs	5–7″, 1–2 tillers, good.	3–8″, good, well tillered.
	1	Do	Fairly thick, 3″	Fine	3–5″ 2–4 lvs., tillering.	Good, 4–6″, some dead.	3–8″, good.

TABLE 58.—*Sowing in denuded quadrats, high prairie, Lincoln, Apr. 16 and May 4, 1920.*—Continued.

Species.	1921. May 10.	1921. June 23.	1921. July 30.	1921. Aug. 31.
1. Andropogon nutans	Well sodded, 2–3"	Fine, 8"	Fine sod, 8–10"	Merged into sod, 1–2 ft., flr. stks. 24".
	1. Dense sod, Poa invading	9"	Good, 6–10"	Merging into sod, 8–12".
2. Andropogon scoparius	Dense sod, excellent, 2–5"	8"	Excel., 8–10", nearly natural sod	Excel., 10".
	1. Dense sod, excel	13", fine	9–12", excel	Excel., 10–12".
3. Aristida purpurea	5 clumps, 2–3"	7", fine	4 good clumps, 5–8"	Fine, 6–7".
	1. 5 clumps, 3–4"	6", good	Many bunches, 4–6" good	Do.
4. Bouteloua gracilis	2", invaded by Poa	Good, 4"	Good, 5–7", beginning to flower	4–6", blooming.
5. Elymus canadensis	Good clumps, fine, 5–7"	15", good	Fine bunches, 12–15", with flr. stks.	Fine, 12–15".
9. Stipa eminens 10. S. setigera	Winterkilled.			
11. Stipa viridula	Dense sod, 2–3"	Fine, 5", tillering	Good bunches	Good, 6".
	1. Good mats, 3–5"	8", fine	Many clumps, 5–8", many dead	Many dead, few green.

Species.	1922. May 16.	1922. June 20.	1922. July 27.	1922. Aug. 24.	1923. June 6.	1923. Aug. 25.
1. Andropogon nutans	Many scattered plants, 4–6", thriving.	7–10", good, lvs. rolling	Good, 6–15"	Fair, 10–20", no flr. stks.	Good, fairly dense sod, 9".	Good, 14–16".
	1. Very open sod, 5–7", thriving.	About 4", some lvs. dying.	Fair, 6–16"	Fair, 9–18", no flr. stks	Rather sparse, abt. 10"	Sparse, fine, 15–17".
2. Andropogon scoparius	Good open sod, 2–5"	3–9", fine	Very abund., fine, 5–10".	Merging into sod, 9", flr. stks. 15"21".	Dense sod, 12".	Fills whole quadrat, 10–14".
	1. Dense sod, 3–5", excellent.	Dense sod, 5–8", exc.	Fine, 6–10"	9", fine, merging into sod.	Dense sod throughout, 8–12".	Dense sod, 10–12".
3. Aristida purpurea	Few clumps, 2–3"	Good clumps	Small plants, 3–6"	Poor, 3–6", badly eaten	Remnants only, 4–5", badly invaded.	Remnants only, 5–6".
	1. About 4 clumps, tallest 4", fair.	Lvs. 5", a few flr. stks. 7".	2–6", many tips brown	Fair, 5–7", no flr. stks	3 clumps, 4–6", fair	Rather poor, 6–8", no flr. stks.
4. Bouteloua gracilis	Several fine clumps, 2–3.5", thriving.	2 clumps, 3–4", good	Good, 2–6", 1 poor flr. stk. 6".	Fair, 3–7", no flr. stks	Scattered but good, 4–8", invaded.	Scattered throughout quadrat.
5. Elymus canadensis	Many good plants, 4–7"	6–7", lvs. rolled	8–12", tips dying	Marker lost		
10. Stipa viridula	Few, badly invaded, 3–4".	4–5", thriving, lvs. rolling.	6–18", scattered	Do.		
	1. Remnants only	Few clumps, 2–3", area quite bare.	A few, fair, 3"9"	Scattering, 5–17", no flr. stks., badly invaded.	Scattering, 6–10", not bady invaded.	Scattering, fair.

Table 59.—*Sowing in denuded quadrats, Phillipsburg, May 7, 1920.*

Species.	1920. June 10.	July 1.	July 10.	Aug. 4.	Aug. 26.
1. Andropogon nutans	Thick, exc., 3–4 lvs., 2–2.5″	Thick, 4–5 lvs., fine, 2–5.5″	Beginning to dry	Thick, 4–7″, good	6–9″, good, 4–5 lvs.
2. Andropogon scoparius	Med. stand, 2–4 lvs., 1–2″	Good, 4–5 lvs., 1–3″	Good	Med. stand, 3–5″, good	Good.
3. Aristida purpurea	Did not germinate.				
4. Bouteloua gracilis	Thin stand, thriving, 1–1.5″, 4–5 lvs.	Good, 1–2″	Beginning to dry	3–4″, not thriving	3″, flr. stalks 6–10″, good.
5. Bouteloua hirsuta	Thin, but thriving; 2–4 lvs., 1″	Very thin, 1–2″, thriving	Do.	Good	2–3″, good.
6. Elymus canadensis	Thick, 2–3 lvs., 2–3.5″	Many dead, fair stand, 4–5 lvs., 2–3.5″.	Affected by drought	Few left, many dead, 2–3.5″	Dead.
7. Kocleria cristata	Very sparse, poor, none over 1″.	Dead.			
8. Liatris punctata	Numerous, 0.5–3″	4–5 plants left, very poor	Very poor, no growth	2 plants left, poor, 1.5″	1 plant, eaten back, 2″.
9. Stipa comata	Thick, 1–2 lvs., 2–3″, nearly all dead.	Dead.			
10. Stipa viridula	Thick, 2–3 lvs., 3–4″, about half have died.	Many dead, fair stand, 3–5″, thriving.	Dying from drought	Poor, many dead, 2–5″	2–6″, poor, many tips, dead.

Species.	1921. June 8.	June 22.	July 25.	Aug. 8.	Aug. 30.
1. Andropogon nutans[1]	Good sod, 3–7″	12–20″, thriving, dense sod	Good, 9–15″	Fine, 15–18″, flr. stks. forming.	Fine, flr. stks. 40″.
2. Andropogon scoparius	Good sod, 3–5″	8–12″, thriving	Excavated for roots.		
4. Bouteloua gracilis	Several fine tufts, 1–2″	4–6″, good, well tillered	Do.		
5. Bouteloua hirsuta	2 or 3 clumps, 2–4″, thriving	6–8″, well developed	Do.		
8. Liatris punctata	2 plants	2 plts., 3–6″, fine	Do.		
10. Stipa viridula	4 or 5 clumps, 2–5″, thriving	7–8″, good	Do.		

[1] During 1922 Andropogon nutans grew well but did not blossom, while in 1923 it made an excellent growth and flowered abundantly.

TABLE 60.—*Sowing in denuded quadrats, Burlington, Apr. 15, 1920.*

Species.	1920. June 11.	1920. July 2.	1920. Aug. 6.	1920. Aug. 24.
1. Andropogon nutans	Abund., 2–3″, 3–4 lvs	Thriving	Good, 4–5″, 4–5 lvs., abund	Thriving, well tillered, 4–5″.
2. Andropogon scoparius	1 or 2 plts., 2″	Dead.		
3. Aristida purpurea	No germination.			
4. Bouteloua gracilis	No germination.			
5. Bouteloua hirsuta	No germination.			
6. Bouteloua racemosa	No germination.			
7. Elymus canadensis	No germination.			
8. Koeleria cristata	No germination.			
9. Liatris punctata	3 plts, 1–3″	1 only, eaten back, poor	Eaten back, poor	2″, 2 lvs., eaten back.
10. Panicum virgatum	2 plts., 6″, thriving	Several, 5–8″, 2–3 lvs., good	Dead.	
11. Stipa coronata	3 plts., 4″	Eaten by grasshoppers, dead.		
12. Stipa setigera	8 plts., 4–5″, thriving	Do.		
13. Stipa viridula	Abund., 3–5″, 2–3 lvs	Thriving, 4–5″, 2–3 lvs	Thriving, 8–10″, 3–4 lvs	Exc., 6–13″, 3–4 lvs., heavily tiltered.

Species.	1921. Apr. 30.	1921. May 20.	1921. June 30.	1921. July 24.	1921. Aug. 29.
1. Andropogon nutans	Greening	Nearly all dead, 1 shoot 2″	5–7″, good, lvs. rolled	No growth, lvs. drying	Fair, 3–6″.
9. Liatris punctata	2″, 2 lvs	5 lvs., eaten back to 3″	Remnants of 1 plant	1 remnant	1 remnant only.
13. Stipa viridula	4″, 20 bunches	4–6″ heavily tillered, thriving.	12–16″, good, lvs. rolled	Fair, no flr. stks., drying	Good, 8–12″, no flr. stks.

Species.	1922. May 20.	1922. June 11.	1922. July 2.	1922. July 16.	1922. Aug. 4.	1922. Aug. 26.
1. Andropogon nutans	1 nice clump, 4″, 3–5 lvs.	Thriving, 9″	Very good	20″, thriving	Exc., 17–20″	Lvs. 20″, flr. stks. 12–30″, thriving.
9. Liatris punctata	1 fine plant, 3″, 10 lvs.	Good, 6″	7″, thriving	10″, excel	11″, buds abund	1 fine plant 12″, flowering abundantly.
13. Stipa viridula	14 clumps, up to 1″ diam., 6–10″.	Fine, 8–14″, thriving	8 fine bunches, 10–14″	12–18″ some tips dead	Exc., many tips dead	12–18″, fine, lvs. slightly rolled.

Species.	1923. July 4.	1923. Aug. 21.
1. Andropogon nutans	2 green shoots only, 15″, little invasion	2 small clumps, 8–15″, will blossom.
9. Liatris punctata	2 fine stalks, 12″, thriving	Now 16″, will flower abundantly.
13. Stipa viridula	Good, many well-tillered clumps, 12–15″	12–18″, thriving, very little invasion.

TABLE 61.—*Seedlings transplanted to high prairie, Lincoln, May 11, 1921.*

Species.	1921 May 25.	1921 June 5.	1921 June 23.	1921 July 30.	1921 Aug. 31.
1. Agropyrum glaucum	Mostly dead, grasshopper-eaten.	2 only, good	2 left, 5″, eaten	Dead.	
2. Andropogon nutans	2 lots dead, other 2 good	Good, 2–3″	2 lots good, 5–6″	More than half dead, rest fair, 4–7″.	2–5″, fair.
3. Andropogon furcatus	Good	Excellent, 2–3″, 2–4 lvs	Good, 5–7″, abund	Good, 6–7″, some dead	Exc., finest 6–8″.
4. Aristida purpurea	Mostly dead, 1 lot green, tips dead.	Half dead	3 lots dead, 1 poor, 2.5″	Dead.	
5. Bouteloua gracilis	Some half wilted, some dead, mostly good.	Good, 2″	2 groups, 2–4″, good	2 groups, fair	2 clumps, 2–4″, good, well tillered.
6. Bouteloua hirsuta	1 lot dead, 3 good	Do	Good	3 groups, 4–7″, fine	4–7″, 2 clumps, flowering.
7. Bouteloua racemosa	2 lots dead, 2 good	3 lvs. 2″, good	Good	1 group only, 5–6″	1 clump 4–5″, exc.
8. Elymus canadensis	Grasshopper-eaten, poor shape.	3 only, fair, eaten back	3 groups, good, 3″	Dead.	
9. Koeleria cristata	2 of 4 lots dead, others fair	1 group good, 1.5″	1 lot left, 2″, eaten	1 good group, 3–4″, exc	1 bunch only, 3–4″, good.
10. Liatris punctata	20 plts., good	Good	3 groups, plts. abund., 3″	Dead.	
11. Stipa comata	Dead or eaten to ground	1 or 2 only, eaten back	Dead.		
12. Stipa spartea	Good	Exc., 2–5″	Eaten to 1.5″, poor	Eaten back, fair, 2–4″, not abund.	2 plts., 3–9″, tillered but little.
13. Stipa viridula	Grasshopper-eaten, some dead, poor.	Good shape, tips eaten	Dead.		

Species.	1922. May 7.	1922. June 20.	1922. July 27.	1922. Aug. 24.	1923. June 7.	1923. Aug. 25.
2. Andropogon nutans	4 plants, 4″	A few clumps, 2–2.5″, poor.	1 lot good, 2–5″	Poor, 3–5″, tips dead	Dead.	
3. Andropogon furcatus	Winterkilled.					
5. Bouteloua gracilis	4 clumps, 2″	Several clumps, good, 3–5″.	2 clumps, good, 2–7″	Fair, 6″, no flr. stks	3 fine clumps, 5–8″	Very good.
6. Bouteloua hirsuta	3 clumps, 0.5″	Fine clumps, 3–4″, thriving.	2 fine clumps, 2–7″	Good, max. 5″, flr. stks. 4–7″.	Good, 3–5″	Good, 4–6″.
7. Bouteloua racemosa	1 plant, 3″	2 or 3 clumps, 3–4″, thirving.	1 good clump, 3–6″	Fair, 4–6″	Good, 4–7″	Fine growth, 5–8″.
9. Koeleria cristata	Winterkilled.					
12. Stipa spartea	1 plant, 4″	1 plt., 8″	½ lvs. dead, area disturbed.	1 or 2 only, max. 11″, poor.	Dead.	

TABLE 62.—*Seedlings transplanted at Phillipsburg, May 19, 1921.*

Species.	1921.				
	June 9.	June 22.	July 25.	Aug. 9.	Aug. 30.
1. Agropyrum glaucum	All 4 lots good, 2–5″	3 lots fair, 1 poor, many dead.	1 lot fair, 6″, rest dead or dying.	1 lot only, 5–7″, fair	Dying.
2. Andropogon furcatus	All 4 lots good, 3–5″, 4–6 lvs.	Fine	Fair, some of each lot 9″	8–12″, narrow lvs. shaded by 28″ B. racemosa.	Poor, dying.
3. Andropogon nutans	4 lots, good, 3–5″	Fine, 3–7″	Exc., some 12″	Heavily tillered, 1 lot nearly dead.	Fair, 8–12″.
4. Bouteloua gracilis	4 lots, fine, 2–3″	A few dead, rest good	Fine, 1–4″	Thick, 3–4″, ½ plants dead	Dry and dying.
5. Bouteloua hirsuta	4 lots, exc., 1.5–2″	Good, tillering, 1–3″	Exc., 1–4″	Good, 2–4″	Fine, 2 flr. stks. at 5–7″.
6. Elymus canadensis	6 lots, exc., 3–4″	Good, 4–5 lvs	Poor, ½ of plants dead	Remnants only, 4–6″, drying	Nearly all dead.
7. Koeleria cristata	4 lots, good, 1″	Some dead	Remnants only	Dead.	
8. Liatris punctata	5 lots, good, abund., 3–5″	Fine, 2–3 lvs., 3–4″	Good	Abund., 3–5″, 2–3 lvs., fine	Good, tallest 5″.
9. Liatris scariosa	2–3″, thick, 4 lots	Good, 1–3″	Good	Fine, abund., 2–3″, little shade.	Eaten to ground.
10. Stipa comata	3 lots, all good	Well tillered, 2–3″	Nearly all dead	Dead.	
11. Stipa spartea	All 6 lots good, 5–6″, tips dead.	Good, tillered, some dead	Some in each lot dying	Fair, 6–10″	Fair condition, little growth.
12. Stipa viridula	5 lots good, 2–4″	Poor, half of plants dead	Nearly all dead	Dead.	

Species.	1922.					
	May 19.	June 10.	June 30.	July 17.	Aug. 3.	Aug. 28.
1. Agropyrum glaucum	One lot only, 4–6″, thriving.	6–12″, few	8–13″, very slender, good	Very slender, tips dead	Tallest 13″, slender, tips dead.	Remnants only, dry.
2. Andropogon furcatus	4 groups, thriving, 2–6″	2 fine bunches, 10″, 2 weak ones, 2–5″.	2 lots good, 11″, 2 slender, 3–4″.	Fair to good, 7–16″	Fair, little growth	8–10,″ very slender, dense shade.
3 Andropogon nutans	A few shoots only	Few, pale, 3–4″	Poor, 1–7″	Lvs. rolled, tips dead	Poor, lvs. half dead	Dried, poor, 6–7″.
4. Bouteloua gracilis	4 clumps, 1–3″, fine	3–6″	4–7″, dense, good	Fine	Somewhat dried, good, 6–8″.	Good normal growth, no flr. stks.
5. Bouteloua hirsuta	4 clumps, 3–4″	Fine row, 12″ long, 3–6″	Thriving, 5–7″	Thriving	Fine, many flr. stks., 4–8″.	Good, well tillered, flr. stks. abund., at 6–8″.
6. Elymus canadensis	Winterkilled.					
8. Liatris punctata	8 plants, 3–8 lvs., 5–6″, thriving.	7–9″	Good, 6–10″	Fine	Poor color, tallest 10–11″.	Several slender, shaded plants, 6–8″.
9. Liatris scariosa	3 plants, 2–4″, good	1 group only, 6″	Thriving	4 plants, 4–7″	Fair	Dead.
11. Stipa spartea	4 thriving groups	4 thin groups, 9–15″, good.	10–18″, slender	Tips dead, very slender	Fair, tips dead, tallest 23″.	Max. 23″, several clumps, drying.

Species.	1923.	
	June 21.	Aug. 22.
1. Agropyrum glaucum	Winterkilled.	
2. Andropogon furcatus	2 stalks, 10″	16″, slender, densely shaded.
3. Andropogon nutans	Fine bunch, 8″	Quite dry, densely shaded.
4. Bouteloua gracilis	Normal, being invaded by Bulbilis	Dense sod, short flr. stks.
5. Bouteloua hirsuta	Normal development	Normal height, has flowered.
8. Liatris punctata	5 fine plants, 11–14″	12–19″, in bud, will blossom abundantly.
11. Stipa spartea	Mere remnants, very delicate	Narrow-leaved remnants, 12–15″, shade dense.

TABLE 63.—*Seedlings transplanted at Burlington, May 20, 1921.*

Species.	June 10.	June 30.	July 24.	Aug. 8.
1. Agropyrum glaucum	3 lots dead, 1 thriving, 1 poor, 2″, tips dead.	1 lot only, half dead, 1–2″	Dead.	
2. Andropogon nutans	5 good lots, 2–3″, 2–3 lvs	Fair, 3–4″, lvs. rolling	Nearly all dead	Dead.
3. Andropogon furcatus	4 exc. clumps, 1–2″, 3–4 lvs	3 lots, 2–3″, wilting	Dead.	
4. Aristida purpurea	4 lots, fair, 1–2.5″	½ dead, 1–2″	Dead.	
5. Bouteloua gracilis	4 good lots, 2–2.5″	Do	Nearly all dead	Dead.
6. Bouteloua hirsuta	7 lots, all thriving, 1–2.5″	Good, 2–2.5″	Poor, many dying	Nearly dead: dead by Aug. 29.
7. Bouteloua racemosa	4 lots, fair, 1″	Remnants only, 1″	Dead.	
8. Elymus canadensis	4 lots, good, 2–3″, 2–3 lvs	Fair, 2–3″, tips dead	Dead.	
9. Koeleria cristata	4 lots, all dead.			
10. Liatris punctata	4 lots, abund., 2–3.5″, thriving	6 plts., 3″	Dead.	
11. Liatris scariosa	2 lots dead, 2 lots 1–3″	Dead.		
12. Stipa comata	2 lots, fair, 1–2″, 2–3 lvs	1 plt., eaten back	Dead.	
13. Stipa spartea	1 lot nearly dead, 2 eaten back, 2 good, 2–5″.	Best lot 3–5″, others remnants	Dead.	
14. Stipa viridula	2 lots dead, 2 good, 2–3″, 2–3 lvs	Dead.		

TABLE 64.—*Sods transplanted to high prairie, Lincoln, Mar. 20-31, 1921.*

Species.	1921. May 5.	1921. June 23.	1921. July 30.	1921. Aug. 31.
1. Andropogon furcatus	Tips of lvs. appear frozen, 1″	Good	Doing well	Fair, thin, 10–15″, not abund.
2. Agropyrum glaucum	6″	Blossoming, 26″	Some flr. stks. dry	Very few, poor, 10–12″.
3. Andropogon nutans	2″	Good	Doing well	Good, 10″.
4. Andropogon scoparius	Just starting, 1″	Good	Do	9″, very thin.
5. Bouteloua racemosa	4″	Fine	Do	10–14″, fair, few heads.
6. Bouteloua gracilis	2″	Good	Fine	Exc., 6–10″, no flr. stks.
7. Bouteloua hirsuta	1″	Good	Very good	4–6″, no flr. stks.
8. Bulbilis dactyloides	Good, 1–2″	Finished blossoming	Do	Exc., 4″, spreading a little.
9. Distichlis spicata	4″	Blossoming, 9″	Mostly dead, somewhat eaten	Nearly all dead, few green, 6–10″.
10. Elymus canadensis	9″	Flr. stks. appearing at 23″	Flr. stks. 36″	Heads at 21 to 40″.
11. Do	9″	Good	Doing well	1 head, 23″.
12. Koeleria cristata	2″	Good	Fine	Good, 8–11″, no flr. stlks.
13. Panicum virgatum	Just starting	Good	Flowering, 2 feet	Well headed at 28–34″, rank growth.
14. Poa pratensis	4″	Blossoming at 12″	Doing well	Fair, 5–9″, has flowered.
15. Spartina cynosuroides	Good, 12″	Fine, 24″	Thriving, 24–30″	Fine, 26–30″, no flr. stks.
16. Stipa spartea	6″	Blossoming at 18″	Doing well	Fair, 20–24″.

Species.	1922. May 27.	1922. June 20.	1922. July 27.	1922. Aug. 24.	1923. June 7.	1923. Aug. 25.
1. Andropogon furcatus	Good, 5–6″	Good, 5–8″	Fair, 6 to 12″, pale	Fair, 1 flr. stlk. 14″	Good	Good, 18″.
2. Agropyrum glaucum	Sparse, 4–8″	Very poor, max. 6″, thin stand.	Very poor, badly grass-hopper-eaten, 4″.	Remnants only, eaten	2 spears only, very poor	Remnants only.
3. Andropogon nutans	Good, 4–5″	Good, 8″	Good, 8–14″	Fair, flr. stlk. appearing	Sparse	Normal, 18″.
4. Andropogon scoparius	Fine, 5–6″	Good	Good, ave. 8″	Fair, dwarfed flr. stks. 12–15″.	Normal	Exc., 12″.
5. Bouteloua racemosa	Good, 3–4″	Rather sparse, 5″, Poa invading.	Badly invaded by Poa	Good, 5–11″, no flr. stks.	Good	Fine growth.
6. Bouteloua gracilis	Good, 4–5″	Good, 4–7″	Fine, av. 7″	Fair, 5–9″, no. flr. stks.	Very poor, badly invaded.	8″, very poor.
7. Bouteloua hirsuta	Good, 2–3″	Good, 3–4″	Thriving, 4–7″	Good, 5–10″, a few flr. stks. 8–9″.	Fine, 4″	Fair.
8. Bulbilis dactyloides	♂ flr. stks. 3″, good	Dry, good, flr. stks. 4″	Fine, many tips dead, av. 2.5″.	Good, spreading	Much invaded, not spreading, has blossomed.	Good.
9. Distichlis spicata	Doing well, 6″	Flr. stks., at 3″, lvs. 6–7″.	Half-dead, a few flr. stks	Very poor, dried and eaten.	Sparse, but good, 8–10″	Remnants only.
10. Elymus canadensis	Good, 1 stk., 12″	1 only, fair, 18″	Practically dead, 1 flr. stlk., 30″.	As on July 27	1 shoot only	1 only, 17″.
11. Do	Poor, 5″, only 2 stks	4 stks. only, poor, 6″	Dead or remnants only	A few remnants	A few shoots, poor, 7″	Remnants, nearly shaded out.
12. Koeleria cristata	Lvs. 4″, flr. stks. 11″, good.	3–4″, badly invaded	Badly mixed, av. 6″	Good, 9″ max	Dead.	
13. Panicum virgatum	Fine, 10″	Exc., 16″, rhizomes spreading.	Good, flr. stks. av. at 18″.	Flr. stks. abundant 22–34″, spreading.	Good, 16″	Spreading, flrs. at 28″.
14. Poa pratensis	Normal, flr. stks. 4″ shorter than normal.	Normal, has seeded	Good, 7″	Fair	Normal	Good.
15. Spartina cynosuroides	Fine, 10″	12–16″, sparse, lvs. narrow and rolled.	Good, 18″, has spread 10″.	Sparse, poor 17–24″	Scattered, poor, leaves narrow, 16″.	Spreading, 24″, no flrs.
16. Stipa spartea	Do	Blossoming, 20″	Good	Good	Normal, has blossomed	Good.

TABLE 65.—*Sods transplanted at Burlington, Apr. 15, 1921.*

Species.	1921.				
	May 20.	June 29.	July 24.	Aug. 8.	Aug. 29.
Plants Watered.					
1. Agropyrum glaucum	Thriving, 5–7″	Flr. stks. 8–18″, abund	Drying up	9–13″, ⅔ plts. dead, others poor.	Heads 9–17″, good.
2. Andropogon furcatus	Fine, 2–4″	Fair, 4–5″	Few good blades, 4–10″, mostly dead.	8–14″, very poor to dead	4 shoots, green, 6–12″.
3. Andropogon nutans	Good, 2–3″	Very poor, 2–4″	Dead.		
4. Andropogon scoparius	Fair, 1″	Do	Very poor shape	Nearly dead	2 remnants, 2″.
5. Bouteloua hirsuta	A few, lvs. only, 2–3″	2″, fair	1 bunch, 2.5″	5–7″, dying or dead	3 plts.
6. Bouteloua racemosa	Thriving, 2–4″	Good, 3–5″	Good	4–5″, good	Fair.
7. Elymus canadensis	Fair, 3–6″	8–12″, fair, no flrs	3 plts. fair, 11″, drying up	9–13″, dried and nearly dead.	1 shoot, 8″.
8. Koeleria cristata	Good, 2–3	4″, poor, no flrs	Eaten down by grasshoppers to 1″.	Dead.	
9. Panicum virgatum	Exc., 4–5″	Badly rolled, 5–7″	Dried	Dead.	
10. Poa pratensis	Good, 2–4″	Nearly dead	Dead.		
11. Stipa spartea	All dead but 1 or 2 green lvs.	No. flrs., 1 stk. 12″	Poor	1 stlk. left 13″, lvs. rolled, ends dead.	1 shoot 16″.
Plants not watered.					
1. Agropyrum glaucum	Good, 5–6″, some lvs. rolled	2 flr. stks. 9–13″, lvs. 8″, fair	Drying out	1 flr. stlk. 14″, seeded, plts. 10″, nearly all dead.	Foliage 8″.
2. Andropogon furcatus	Good, 2–3″	4–5″	Practically all dead	Dead, no lvs. over 7″.	
3. Andropogon nutans	Do	Dug up for root development.			
4. Andropogon scoparius	Fairly good, leaf tips dead, frayed in wind.	Fair, 5″	Very poor, dying	Very poor, dry	4 or 5 shoots revived.
5. Bouteloua hirsuta	4 or 5 shoots, 2″, good	Fair, 2–4″	Poor shape, 4″	Dead.	
6. Bouteloua racemosa	Fair, 2–3″	Do	Fair, 4.5″	All dead but 1 clump 4″, this nearly dead.	Dried, apparently dead.
7. Elymus canadensis	Poor, 1 shoot only	Nearly dead	Dead.		
8. Koeleria cristata	A few green lvs., poor, mostly dead.	Few lvs., poor	Almost entirely dried out	Dead.	
9. Panicum virgatum	Exc., 5–8″	Dug up for root development.			
10. Poa pratensis	Good, 2–3″	Fair, no flrs	Dead.		
11. Stipa spartea	A few green lvs., poor, mostly dead.	Dead.			

TABLE 65.—*Sods transplanted at Burlington, Apr. 15, 1921*—Continued.

Species.	1922.					
	May 20.	June 11.	July 2.	July 16.	Aug. 4.	Aug. 26.
Plants watered.						
1. Agropyrum glaucum	8", spreading into short-grass sod but little.	Good to 12", flr. stks. appearing.	Heading freely, 18–20", spreading a little.	5 flr. stks., lvs. tightly rolled, fair.	Spread slightly, lvs. 12", flr. stks. 18", no flr. stks on plants in sod.	10" half dry.
2. Andropogon furcatus	4", fair	3 or 4 shoots, fair, 5–7", no flr. stks.	Sparse, 6–9", thriving	Max. 11", fair	2 small clumps, 6–12", fair.	A few stks. only, 7–13" green lvs. rolled.
4. Andropogon scoparius	1 or 2 remnants only	1 shoot 2"	Dead.			
5. Bouteloua hirsuta	3 plts., fair	1.5", fair	Sparse, but flowering at 4–5".	6", good	Good, 6"	Fair, no flr. stks.
6. Bouteloua racemosa	Thriving, 3–4"	Fair	Exc., 5–6"	7", fine	Exc., 7"	1 flr. stk. at 18".
7. Elymus canadensis	2 stks. 4–8", fair	2 stks., fair, 9–11"	2 stks. only, 8 and 12"	2 stks., 8 and 16", tips and lower lvs. dead.	2 stks. 8 and 18", no flr. stks.	1 flr. stk. at 22", head small.
11. Stipa spartea	12", 2 or 3 shoots, good	3 stks	18", 3 stks., no flrs	6 stks., 7–24", some tips dry.	Small clump, 12–18", tips dead to 6".	Fair.
Plants not watered.						
1. Agropyrum glaucum	Fine, 4–5"	Fair, short flr. stks. 7–10", drying.	Flr. stks. only 9–13", spikes small, lvs. dwarfed.	Very dry, 10 flr. stks. 12", lvs. 8–10".	Lvs. ave. 8", flr. stks. 12–13", ½ have died, heads small, has not spread out of block.	Nearly dry, 7".
4. Andropogon scoparius	Winterkilled.					
6. Bouteloua racemosa	1 small clump 2"	Small clump 4"	3–4", fair	Rolling badly, tips dead, 4".	Small clump, 3–4"	Lvs. tightly rolled, poor.

Species.	1923.	
	July 4.	Aug. 21.
Plants watered		
1. Agropyrum glaucum	Fair, 15", little spread	Fair, 12–18", no flr. stks.
2. Andropogon furcatus	Winterkilled.	
5. Bouteloua hirsuta	Do.	
6. Bouteloua racemosa	Good, 10"	Exc., 3 flr. stks., 15–26".
7. Elymus canadensis	2 shoots only, 8"	2 shoots, no heads, very poor.
11. Stipa spartea	Small bunch, 24", no flr. stks	Good bunch, 26".
Plants not watered		
1. Agropyrum glaucum	Fair 11"	Fair, has not spread.
6. Bouteloua racemosa	Winterkilled.	

TABLE 66.—*Sods transplanted to gravel-knoll, Lincoln, Apr. 20, 1920.*

Species.	1920.			1921.			
	June 28.	Aug. 13.	Aug. 30.	May 11.	June 23.	July 30.	Aug. 31.
1. Agropyrum glaucum	No flr. stks., 12″	12–14″, poor, no flr. stks.	Few green stks. 24″, mostly dead.	Fair, 7″	Very poor, dying	Sparse, 7–10″	Poor or dying.
2. Do	18″	13–15″, no flr. stks., fair.	Good, 1 flr. stk 22″	6″, fair	Poor, 8–10″	Poor	Poor, 6″.
3. Andropogon furcatus	6–8″, some dead at base, others half wilted.	Mostly dead, 7–9″	8–10″, half dead, no flr. stks.	Fine, 6″	18″, good	Many tips dying	Half dried, 10″, no flr. stks.
4. Do	Almost entirely wilted.	8–10″ poor	⅔ dead, no flr. stks.	Do	12″, good	19″, 2 heads out	Headed 24–28″, good.
5. Do	Do	5–7″, drying up	6″, ⅔ dead	Do	Poor, 7″	9″, some dying	Drying, 7″.
6. Andropogon nutans	Wilting	9″, nearly all dead	Poor, 2–3″	4–5″	Good, 15″	Fair	10–12″, good.
7. Do	Suffering from drght.	9″, fair	Good, 9–10″	4–6″, fair	Good	Poor, eaten down to 9″.	Good, 10″.
8. Andropogon scoparius	Fair, wilting	8–10″, leaf tips dead.	Half dead, no flr. stks.	Good, 6″	14″, good	16″, good	Flr. stks 13″, drying.
9. Do	Suffering from drght.	7–9″, poor	7″ or less, many dead.	Do	Lvs. rolling	Fair 9–12″, some dying.	Much wilted, 9″.
10. Do	Wilting	Nearly all dead	Dead.				
11. Bouteloua racemosa	Fair	7″, fair, no flr. stks.	9″, no flr. stks.	4″	Good, 5″	Good, 6–9″	6″, good, seeding at 18″.
12. Do	Do	7″	Good, no flr. stks.	3–5″	Good	Good	Good, 10″.
13. Elymus canadensis	20″, lvs. rolling	Heads normal, 24–28″, seeds nearly ripe.	Flr. stks. abund., 28″, fine.	Vigorous growth, 10″.	Good, flr. stks. appearing, 24″.	6 heads, 35″	Flr. stks. 24–30″, plants dried up.
14. Do	Drying out	Flr. stks. 30″, heads normal, seeds ripe.	Flr. stks. abund., 28″ fine.	Few stks. 7″	1 stk. 2 ft., good	1 stk. only	Dead.
15. Do	Lvs. rolling	Flr. stks. 28–34″, heads normal ripe.	Do	Do	Poor, 10–12″	Poor, 13″	Nearly all dead.
16. Koeleria cristata	18″, dry at base	12–14″, lvs. 5–6″	Good	Dead.			
17. Do	Nearly dry	Flr. stks. 15″, seeds ripe.	Many flr. stks. 19″.	Poor	9″, no flr. stks., fair.	Sparse, 11″	Poor, 7″.
18. Do	Do	Flr. stks. 14″, seeds ripe, lvs. dried.	Do	Heads appearing, fine	Very poor, 10″	Died down to 6–7″, poor.	Dead.
19. Panicum virgatum	Lvs. partly wilted, 6–10″.	Good, 12–14″	11″, fair, no flr. stks.	Fine, 7–10″	18″, good	Panicles abund., 30″.	Headed at 20–30″, good.
20. Do	Wilting	10–12″, good	Do	Do	12″, good	Few heads, tallest 14″.	Fair, flrs. to 16″.
21. Do	Drying out	10–12″, fine	Panicle, 8–12″	Do	12″	Heading out at 15–24″.	Fair, flrs. to 16″.
22. Poa pratensis	22″, seeded	Flr. stks. 18–22″, seeds ripe.	Normal	Good, 8″, heading out.	Fair, no flr. stks.	Normal	Normal.
23. Do	Seeded and drying	Flr. stks. 18″, lvs. dry.	Dead.				
24. Spartina cynosuroides	Good, 15–16″	Good	24″, no flr. stks., good.	12–15″ good	Good, 21″	Good, 27″	24–28″, good.
25. Do	Good, 16–17″	20–23″, no flr. stks., fair.	Do	Good	15″, poor	Do	25″, good.
26. Stipa spartea	2–2.5 ft., awns twisting earlier than elsewhere.	Flr. stks. 24–26″, seeds fallen.	About normal	Excellent, 10–12″	Good 18″, no flr. stks.	24″	Good 18″.
27. Do	Do	Flr. stks. 15″, seeds fallen.	Good, 15″	Good	24″, no flr. stks., good.	Sparse but good, 18″.	Good, 15–18″.
28. Do	Do	Flr. stks. 21″, seeds ripe, fallen, 18–20″.	Do	Good, 15″	Good, no flr. stks.	Small clump, good, 26″.	Fine, 24–28″.

TABLE 66.—*Sods transplanted to gravel-knoll, Lincoln, Apr. 20, 1920*—Continued.

Species.	1922.				1923.	
	May 27.	June 20.	July 27.	Aug. 27.	June 7.	Aug. 25.
1. Agropyrum glaucum	1 shoot only, 6″, poor	Dead.				
2. Do	Few stks., 6–8″, fair	A few shoots only to 11″.	1 or 2 plants 11″, no flr. stks.	Very sparse, 11″	A few poor plants, 12″	11″, eaten back.
3. Andropogon furcatus	Fine bunches, 2–3″	4–5″, good but lvs. rolling.	Good, 8–14″	Poor, nearly dry	1 bunch only, 5–6″	16″, good.
4. Do	Fine, 7″	Good to 8″, badly rolled	Fine, 12–18″, 1 flr. stk. appearing.	2 flr. stks., drying	Exc., 12″	18″, will flower.
5. Do	Good, 4″	4–5″, half dry	Nearly all dead	Dead.		
6. Andropogon nutans	4–6″, good	6–8″, badly wilted	Good, 8–12″	Dried	Has tripled original area, exc., 16″.	Exc., 18″.
7. Do	Good, 4–6″	8–9″, fair, lvs. rolled,	Exc. 13″, 1 flr. stk. appearing.	Dry. 2 flr. stks. 15 and 18″, not fully out.	Good, 16″	20″, spreading.
8. Andropogon scoparius	Good, 5–6″	6–7″, good but lvs. rolling.	Fine, 10–15″	Poor, nearly dry	Good, 11″	Good.
9. Do	Good, 6″	4–5″, rolling badly	Sparse, fair, 9″	Nearly dead	Dead.	
11. Bouteloua racemosa	4–5″, good	3–4″, badly wilted	Good, 3 flr. stks., 10–18″.	Lvs. rolled, tips dead, 1 flr. stk. 19″.	1 small clump, 9″	Fair, 8″.
12. Do	4″, good	4–5″, fair, lvs. rolled	Good, 3 flr. stks, 14–17″	As on July 27	Good, 10″	12″ good,
13. Elymus canadensis	2 stks. only, 6–9″	2 stks. 8″, half dead	Dead.			
15. Do	Poor, 4 or 5 stks., 6″	4–5″ only, dead or dying	A few poor plants, 5–7″	Dead.		
17. Koeleria cristata	Did not grow in 1922.					
19. Panicum virgatum	Exc., 8–10″	13″, fine but rolling	Exc., spreading on all sides, max. 22″, many flr. stks.	Many dwarfed panicles at 18″.	Fine, spreading widely	Good, flowering at 26″.
20. Do	Exc., 10″	10″, wilting	Sparse, max. 17″, no flr. stks.	Poor, 1 poor flr. stk. 12″	Good, 15″	Fair.
21. Do	Fine, 7–9″	12–13″, fair to good	Fine, many heads at 15″	Good, flr. stks 12–26″	Fine, has doubled area	Exc.
22. Poa pratensis	Did not grow in 1922.					
24. Spartina cynosuroides	Good, 15–20″, has migrated 6–8″.	22″, narrow-leaved and rolled.	Very little, good, 16–20″, spreading.	Good, 20–28″, no flr. stks.	Sparse, 20″, has spread 12″.	Sparse, but good.
25. Do	Good, 15–20″, migrating	Narrow-leaved plts. 13″, rolled.	1 clump, 13–18″, fair	2 poor shoots, 1 flr. stk. 16″.	Has spread 24″	Sparse but good, 34″.
26. Stipa spartea	Normal flowering	Normal, has flowered	Good 14–22″	Fair, 22″	Good, has blossomed	Good.
27. Do	Small plant, flr. stks. 28″, blooming.	Normal, seeded	Good, tips dead, 18–21″ 1 flr. stk.	Do	As above	Small bunch, 22″.
28. Do	Do	Do	Fine to 28″, 1 flr. stlk	Do	Normal, but no flr. stks	Small bunch, 25″.

TABLE 67.—*Sods transplanted to low prairie, Lincoln, Mar. 22 to Apr. 24, 1920.*

Species.	1920.		1921.			
	Aug. 13.	Aug. 30.	May 18.	June 27.	July 25.	Aug. 31.
1. Agropyrum glaucum	Good	Good, flr. stks. 23″	Badly invaded, lvs. narrow, 7–12″.	Poor, no flr. stks	Poor	2 ft. attenuated, no flr. stks.
2. Do	Flr. stks 24″, good	Fine, flr. stks. 33″	Poor, few thin lvs. left, 12–14″.	Poor, almost gone	Very poor	Dead.
3. Andropogon nutans	Flr. stks. 2–3 ft	Good	Good, 12–20″	Normal	15–24″	Normal, 4–5 ft., with flrs.
4. Andropogon scoparius	Blooming, badly invaded, fairly good, 18–20″.	Flr. stks. abund., 24–28″.	Poor	21″, good	Flr. stks. 30″	3 ft., in bloom, exc.
5. Do	Good	Flr. stks. abund., 24–28″.	Normal, 6–8″	Do	Flr. stks. 30″	40″, exc.
6. Do	Do	Good, flr. stks. 16″	Thriving, 8–14″	Good, 12–18″	Fine	Fine, flr. stks. 36″.
7. Do	Do	13–14″	Thriving, dense, 5–7″	Do	Fair	Poor, no flrs.
8. Andropogon furcatus	8–12″, fine	No. flr. stks	Good	Thriving, 18–21″	Flr. stks. 40″	Exc., flrs. 4.5 ft.
9. Do	Good, beginning to bloom.	Thriving, flr. stks. 48″	Good, 12–18″	Good, 25–30″	Do	Normal, 4–4.5 ft.
10. Bouteloua gracilis	Thriving, flr. stks, 12″	Good, flr. stks. 16″	Thriving, 5–8″	12″, no flr. stks	Badly invaded	Fine, 10–12″.
11. Do	Flr. stks. 2 ft. or more	Fine, flr. stks. 2 ft	Fine, 6–8″, some invasion by Andropogons.	8–10″, good	8–12″	Exc., 6–12″, but few flrs.
12. Bouteloua racemosa	Badly invaded	Exc. flr. stks. with seed 29″.	Dead.			
13. Bulbilis dactyloides	Has blossomed, badly shaded, thriving.	Good, 8″, stolons abund. but not rooting.	Scattered plants, suffering badly from invasion, 5–6″, mostly dead.	⅔ dead, some pistillate flrs.	Densely shaded, half dead.	Nearly all dead, shaded.
14. Distichlis spicata	Fair	Good	Main area dead, 2 plants poor.	Scattered, no flrs., poor.	Fair to dying	Very poor, nearly all dead.
15. Elymus canadensis	32–36″, fine	Flr. stks. 40″	Good, 20″	Heading at 39″	Flr. stks. 3.5 ft., big heads.	Flr. stks., 40″.
16. Do	Do	Flr. stks. 30″	Suffering from competition, only 10″.	26″, no heads	Do	Flr. stks. 30″, heads smaller, plants poor.
17. Do	Fine, in flr	Good, heads abund., 40–46″.	Good, normal	About to head, 1–2.5 ft.	Flowering at 4.5 ft	4.5–5 ft., big heads.
18. Do	Fine	Do	Do	Do	Flowering	3 ft., big heads.
19. Koeleria cristata	12–15″, in seed	Good, flr. stks. 20″, abund.	Dead.			
20. Do	Do	Do	7–9″ badly shaded, lvs. narrow, no flr. stks.	About 9″, poor	Poor	Remnants 3–5″, badly shaded.
21. Do	Do	Do	8–11″, shaded, no flr. stks.	12″, no flrs	Do	Remnants, 6″, badly shaded.
22. Panicum virgatum	24″, blooming	Fair	Good, 12–18″	Normal	Flr. stks. 3.5–4.5 ft	Flrs. 3–4 ft.
23. Poa pratensis	Good	Good	Good heading	Seeded, normal	Good	Being shaded out.
24. Spartina cynosuroides	36″, no flr. stks., exc	40–48″, no flr. stks	Thriving, 12–15″	Exc., 39″	3.5–4.5 ft	4.5 ft., exc., no flr. stks.
25. Stipa spartea	Good	Normal	Dead.			
26. Do	Do	Do	2 ft., few lvs., flrs. forming.	33″, has fruited	Good	Good, 2 ft.
27. Do	Do	Do	Dead.			
28. Do	Do	Do	Few lvs. left, spindly, no flrs., 12–13″.	36″, good	Fair	2 ft., badly shaded.

TABLE 67.—*Sods transplanted to low prairie, Lincoln, Mar. 22 to Apr. 24, 1920*—Continued.

Species.	1922.				1923.	
	May 27.	June 22.	July 28.	Aug. 23.	June 7.	Aug. 25.
1. Agropyrum glaucum	Spreading several ft., lvs. narrow 15".	Stks. sparse, slender, lvs. narrow, 15", no. flr. stks.	Poor, very few plants	Dead.		
3. Andropogon nutans	Fine, indis. from native sod.					
4. Andropogon scoparius	Good	Lvs. 12–14", very slender.	Very sparse, 14–16", poor.	Very slender, sparse, 14".	Dead.	
5. Do	5–6", good	Fine bunch 18", lvs. very slender.	Fine, 29"	Fine sod, many flr. stks, 42".	A few green shoots, 6–10".	Poor.
6. Do	Under grass mulch, coming slowly.	Attenuated, fragments only.	Dead.			
7. Do	Dead.					
8. Andropogon furcatus	Good, 3–5", dense sod	Dense sod, 9", exc.	Rather sparse, good, 18–24".	Good to 23", sparse	Fine, 15"	Normal development.
9. Do	Fine, indis., from native sod.					
10. Bouteloua gracilis	Invaded, lvs. slender, 5–6", fair.	Very sparse, a little invasion both ways, lvs. 6–7", no flr. stks.	Remnants	Remnants, densely shaded.	Dead.	
11. Do	Lvs. slender, good, 8–9".	Densely shaded, very delicate, 6–9".	Max., 13", few plants, very weak.	Poor remnants	Dead.	
13. Bulbilis dactyloides	Remnants, under 1.5" débris.	Dead in major area, though not invaded, a few bloomed.	Sparse, but fair, 3–6"	Dead.		
14. Distichlis spicata	Did not grow in 1922.					
15. Elymus canadensis	Few stks., 12–17", good.	24", good, lvs. narrow	1 flr. stalk. 34", 1 flr. stlk. 40".	As on July 28	Good growth, 24"	Normal.
16. Do	2 or 3 stks. 9", poor	A few stks. only 17", lvs. narrow.	No flr. stks., max. 31"	Very sparse	As above	As above.
17. Do	Several stks. 18", good	Abund., 24"	Good, 1 poor flr. stk. 30", foliage 40".	As on July 28	Quite good, 20–28"	Headed at 39".
18. Do	12–13", good	Good, 20"	1 flr. stlk. 40", good, foliage 27".	Do	Good, about 24"	Headed.
20. Koeleria cristata	Did not grow in 1922.					
21. Do	9", good, no flr. stks.	Lvs. 12", densely shaded, no flr. stks.	Very little, 7–14", dying.	Very little, drying	8–12", good	Fair.
22. Panicum virgatum	Became indistinguishable from the native sod.					
23. Poa pratensis	5–7", no flr. stks., dense shade.	Straggling remnants	Dead.			
24. Spartina cynosuroides	Good, 2 ft.	Fine, 30"	Good, 50"	Normal	Good, 24–30"	Normal growth.
26. Stipa spartea	15–18", awns appearing, undersize.	In seed, 3 ft., lvs. 20", good.	Very few to 3 ft.	Max. 40"	Good clump, heading at 28".	Normal.
28. Do	Plants only 12", no flr. stks.	Lvs. 24", good, seeded at 27".	Good, 35 to 50"	Fine, max., 50"	Good clump, 24", no flr. stks.	Do.

TABLE 68.—*Sods transplanted to salt-flat, Lincoln, Apr. 24-26, 1920.*

Species.	1920.		1921.			
	June 15.	Aug. 30.	May 18.	June 27.	July 3.	Aug. 30.
1. Agropyrum glaucum	Normal, flr. stks	13", poor, heads at 27"	Good, 8–10"	Poor	Fair, no flr. stks	Poor.
2. Andropogon furcatus	Suffering from drght	Lvs. 10–15", good	Good, 7–10"	Fair, 12"	18", good	17–24", 5 heads.
3. Do	Do	Do	8–10"	12", good	10–18"	Good, no flr. stks.
4. Andropogon nutans	Good	12–14", good	Badly rolled, very poor, 5–6" only.	Very poor, 6"	Fair, 10"	10", drying, no flr. stks.
5. Andropogon scoparius	Very poor	Some new lvs., practically dead, 6".	5–7", poor, mostly dead	Very poor	Distichlis invaded, very poor, 4".	5–10", no flr. stks., invaded.
6. Bouteloua gracilis	Good	Normal, flr. stks. 14"	Good, 3–6"	6", fair	Fine, 8", several heads	Fine, 7", many heads.
7. Bouteloua racemosa	Poor	9", no flr. stks	5–9"	12"	Good	Dead.
8. Distichlis spicata	Normal	Normal	Normal development	Normal	Normal	Normal.
9. Elymus canadensis	Good	Normal, seeded at 24–27".	Pale, fair, 8–14"	12–18", yellow, flowering delayed.	Good, 17–30", small heads.	Heads short, pale but fair, flrs. 23–30".
10. Do	Do	Do	Very poor, 6–9"	Poor, no flr. stks. 13"	Sparse, 3 small heads, 13–20".	Nearly dead, flrs. 18–22".
11. Koeleria cristata	Normal flr. stks	Flr. stks. abundant 17"	Fair, short, lvs. 5–7", 2 flr. stks.	Very poor, 5–8", no flr. stks.	Fair, 1 head 13"	5", fair.
12. Do	Good	Flr. stks. abund., 17"	4–5", very poor, drying	Poor, flr. stks. 4–13"	A little left	Fair.
13. Panicum virgatum	Suffering from drght	Abund., panicles 24–32"	Exc., 18–22"	Fine, 26"	Rank, numerous heads to 40".	34–40" ,good.
14. Do	Do	8–9", no flr. stks	Fair, 6–8"	10–11"	Good, heads to 40"	Fair.
15. Poa pratensis	Good	Nearly normal	Fair, lvs. short 5", flr. stks. 12".	3–5", poor, flr. stks. 10"	Good, several heads	Fair, 6".
16. Spartina cynosuroides	Lvs. rolling	24", no flr. stks	Good, 12–15"	20–24", fine	Good, 24 to 34"	25–28", no flr. stks.
17. Stipa spartea	Seeded, plant dwarfed	Nearly normal development.	Poor, drying, 6–10"	9–10", no flr. stks., tips dead.	Good, 11–17", no flr. stks.	12–16", no heads, invaded.

[1] Planted here in 1919.

TABLE 68.—*Sods transplanted to salt-flat, Lincoln, Apr. 24–26, 1920*—Continued.

Species.	1922.				1923.	
	May 27.	June 22.	July 28.	Aug. 23.	June 7.	Aug. 25.
1. Agropyrum glaucum	8″	Only isolated shoots, max. 12″, a few flr. stks. at 18″.	One, 12–15″	No flr. stks. lvs. 16″	Normal, flowering at 22″.	Good.
2. Andropogon furcatus	Fair, 3–4″	9–11″, fine, thriving	Exc., 18–22″	Fair, no flr. stks	Excellent, 15″	Good, 18″.
3. Do	5–7″	Fair	9–11″, thriving	Good clump, thick flr. stks. 24–35″.	Good	Fair.
4. Andropogon nutans	2–3″, tips dead	Poor, 4″, badly wilted	Good, 10–14″	Short, fair, no flr. stks	Remnants, less than 9″	1 shoot only, 25″.
5. Andropogon scoparius	Fair, 3–4″	Fair	Not thriving	Good, 9–12″, no flr. stks	Good, 9″	Remnants, 2–3″.
6. Bouteloua gracilis	Good, 4″ excavated.					
8. Distichlis spicata	5–6″, spikes appearing	Normal	Normal flr. stks., 8″	Normal	Normal	Has seeded.
9. Elymus canadensis	Dwarfed, no stks. over 7″.	11″, lvs. rolled, poor, dead at base.	Many dwfed. heads 12–18″, fair.	Poor color, sparse	Very poor, yellow	20″, no flr. stks., lvs. narrow.
10. Elymus canadensis	Did not grow in 1922.					
11. Koeleria cristata	Heading at 4–9″, small	Flr. stks 5–13″, lvs. not abund., 5″.	5–8″, good	Fair	Heading at 13–20″	Badly invaded, fair.
12. Do	Flr. stks. 3–4″ only	Seeds ripe at 6″, lvs. rolled, many dead, poor.	Rather poor, 5–7″, eaten some.	Poor, dry	Poor, heading at 10–12″	Fair.
13. Panicum virgatum	Fine, 12″	Fine clump	Fine, spreading 25″, panicles at 30″.	Numerous panicles 22–40″ spreading.	Normal	Flr. stks. 34″.
14. Do	2–3″, poor	Dead.				
15. Poa pratensis	Flr. stks. 10″, dwarfed	Drying, invaded by Distichlis.	Poor, short, dry, eaten back.	Dry, poor	Normal, in flower	Fair.
16. Spartina cynosuroides	10–14″	Spread 6″ on 2 sides, 16–18″, good.	Good, 18 to 27″	Good, 24–32″, no flr. stks.	Fair	A few shoots, 40″.
17. Stipa spartea	7″, poor, 2 or 3″ of lvs. dead.	Fragments 8″, lvs. rolled	12–16″, good, sparse	Small bunch, 13–18″ poor.	Very small bunch, no flr. stks.	Dwfed., 12″.

TABLE 69.—*Sods transplanted to swamp and Poa zone,[1] Lincoln, Apr. 24, 1920.*

Species.	1920. May 15.	June 2.	June 15.	July 15.	Aug. 5.	Aug. 30.
1. Agropyrum glaucum	8″, good	Fair	Some basal lvs. dead, flr. stks. 18–28″.	Lvs. nearly dead at base, tall, slender, few small spikes.	24″, basal lvs. not dead, not thriving.	A few slender plants left, 12–16″, poor.
2. Andropogon furcatus	No growth	Small group only, 4″, tips dead.	5 shoots, 4 lvs., each 5″	Poor, 5″, ends of lvs. dead.	Poor, 6–8″, tips dead	Dead.
3. Andropogen nutans	No green parts	6″	2 or 3 shoots only, 9″	Much attenuated, 13″	12–14″, very attenuated	Do.
4. Andropogon scoparius	Greening a little	Dead.				
5. Bouteloua gracilis	A few green sprouts	Dead.				
6. Bouteloua racemosa	Sod green	6″	Blue grass invaded, dead			
7. Distichlis spicata	Fair	5 or 6″	Beginning to bloom, 12″, plants attenuated.	Fair	Fair, in seed, 16″	Not thriving, badly invaded.
8. Elymus canadensis	10″, fine	9″, many tips dead	16″, many basal lvs. dead to 6″.	Lvs. dead to 9″, stks. 18–22″, heads small, plants sickly.	All but upper 2 or 3 lvs. dead, 2 flr. heads 1.5–2″, in bloom or seed.	New shoots near base, stems rotted near ground.
9. Koeleria cristata	6″	Heads nearly out at 4–8″, most lvs. dead.	4–8″, in blossom, flr. stks. rotted at base, few basal lvs. still green.	Dead, Typha in its place.		
10. Panicum virgatum	No green parts	6″, thriving	Thriving, 14″	18–23″, stks. slender, lvs. narrow, color yellow green, fair.	Fair, 24–30″	22–30″, attenuated, no flr. stks., many basal lvs. dead.
11. Poa pratensis	Beginning to flr., 6″	21″, full bloom, thriving	In seed, 24″, flourishing	Badly invaded by Heleocharis.	Poor	Under Heleocharis, which is 24–36″ high.
12. Spartina cynosuroides	10″, normal	20″, thriving	Flourishing, 30″	40″, flourishing, flr. stks. 53″, seeds ripening.	65″ max., blossom and seed.	Flourishing, in seed, over 60″.
13. Stipa spartea	9″, half lvs. dead	Leaf ends dead, for 3–5″, 12″, no flrs., not thriving.	No flr. stks., nearly dead	Dead.		
Transplanted into the Poa zone						
1. Agropyrum glaucum [1]	12″, better than in swamp.	15–20″, thriving	Flr. stks. abundant, 36″	Good	Good	Flr. stks. 37″, seed, fair.
2. Andropogon furcatus [1]	New growth, 2″	4–6″, tips dead	6–9″	Good, 10–13″	Good, 12–15″	Good, 14–18″, slender.
3. Andropogon nutans [1]	Just beginning	Dead.				
4. Andropogon scoparius	Abund. new growth, 1″	Dead.				
5. Bouteloua gracilis [1]	New growth abund., 1.5″	2–4″, sickly	Lvs. half dead, green ones 5″.	Half dead, 5–7″, invaded by Scirpus.	Many lower lvs. dead to 8″, no flrs.	No flr. stks., very poor.
6. Bouteloua racemosa [1]	Just beginning	Not thriving, 3–4″	Good	2 plants, 5″	Fairly good, 8–10″, badly invaded.	Dying from invasion.
7. Distichlis spicata [1]	8″	9″	Beginning to bloom, 10″, not abundant.	Nearly normal	Nearly normal	Good.
8. Elymus canadensis [1]	10″, fine	12″, stems red at bases for 5″.	Basal lvs. dead to 6″, plants 17″.	Dwfed., flr. stks. 28″, poor color.	Fair, max. 36″, basal lvs. dead to 12″, spikes 2–4″ long.	Lower lvs. dead flr. stks. 2.5–3 ft., small heads.
9. Koeleria cristata [1]	Fine, 6″	6–9″, plants dwfed., half lvs. dying or dead.	Nearly dead, flr. stks. rotted at base, has flowered but dried up.	Dead, except one remnant.	Dead.	
10. Panicum virgatum [1]	A few shoots, 1″	5–7″	Good, 8–12″	Good, 24–29″	Blossoming, max. 34″, fine.	Good, normal panicles, 40–44″.
11. Poa pratensis [1]	Beginning to flr. 6″	17″, flowering	In seed, 24″	Fine	Fine, invaded by Heleocharis.	Nearly normal.
12. Spartina cynosuroides [1]	6″, poor	15″	23″, flourishing	37″, no flr. stks.	Blossoms 68″, flourishing.	Exc. flr. stks. 5.5 ft.
13. Stipa spartea [1]	8″, ⅓ lvs. dead	Awns appearing, dwarfed, 11″, half lvs. dead.	No flrs., flr. stks. 10″, with awns protruding, plants ¾ dead or dry.	Dead.		

[1] Transplanted into the Poa zone.

TABLE 69.—*Sods trnnsplanted to swamp and Poa zone,*[1] *Lincoln, Apr. 24, 1920*—Continued.

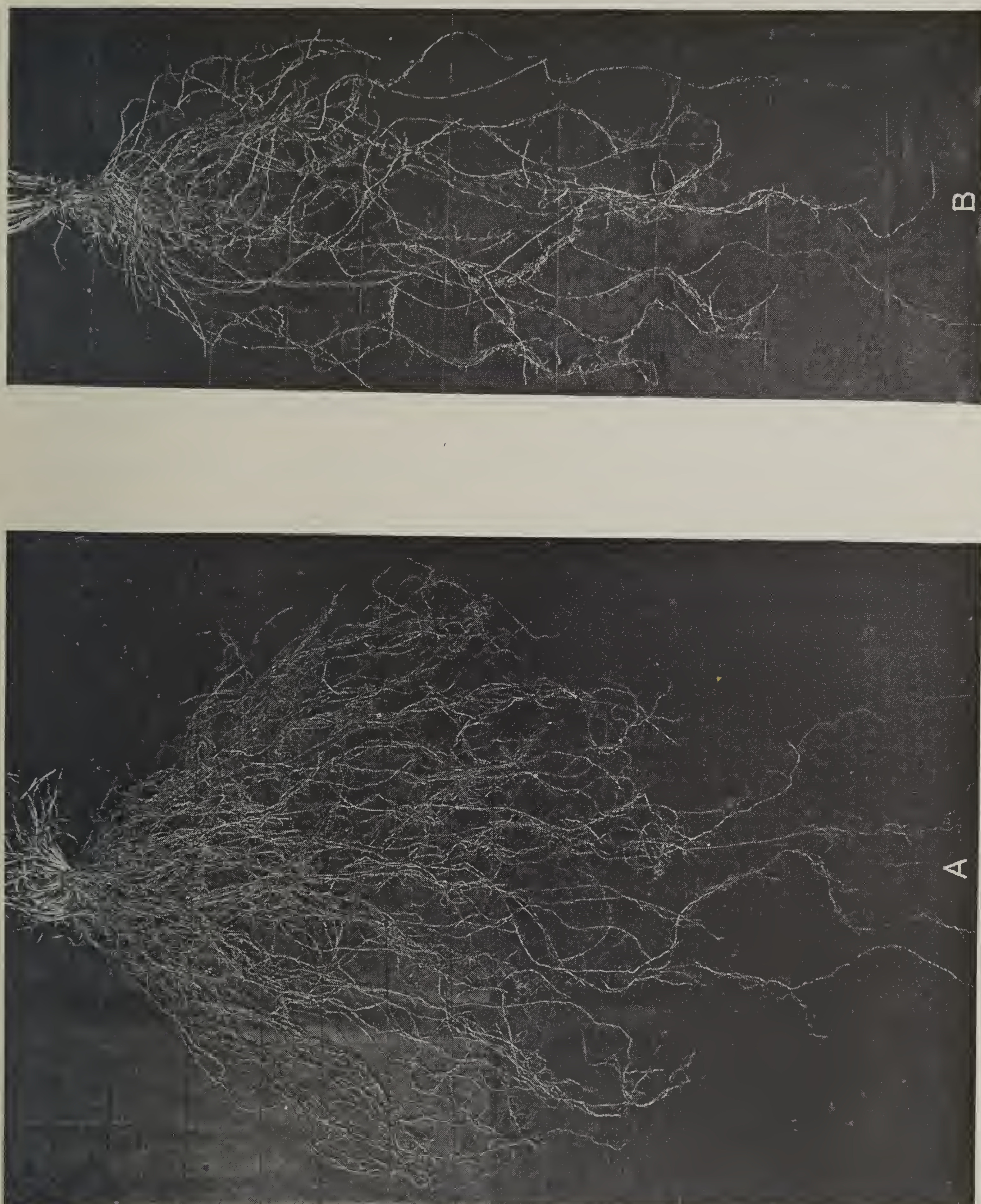
Species.	1921.				1922.		
	May 10.	June 6.	July 30.	Aug. 31.	June 20.	July 27.	Aug. 24.
1. Agropyrum glaucum	Very narrow lvs., few stks. 4–6".	Few, very slender narrow-leaved stks. 20".	Dead.				
7. Distichlis spicata	Good, lvs. narrow, 6–8".	Fair, 16", stems slender.	Fair	Remnants only, nearly dead.	Several stks 12", lvs., slender.	Very few to 10", fair.	Max. 13", few plts. poor.
8. Elymus canadensis	Poor, 6", narrow lvs.	Pale and slender stks., weak, lvs. short 20".	Few stks. to 15", very slender and poor.	Remnants only 8–13", very poor.	Nice clumps 20", rather dwarfed.	A few, good, 25", no heads.	1 flr. stk. 24", sparse.
10. Panicum virgatum	Few lvs. 2–3"	Fine bunch, 32"	Fair, 32", just blossoming.	36", slender, fair	Several shoots 12", lvs. slender.	Good, 30", 2 or 3 heads emerging.	2 flr. stks. 38–40", good.
11. Poa pratensis	Covered by Heleocharis.	Remnants only, poor.	Dead.				
12. Spartina cynosuroides	Normal	Normal, 36"	36–42"	Normal	Normal 30"	Not disting. from surrounding vegetation.	As on July 27.
1. Agropyrum glaucum[1]	Did not appear in 1921.						
2. Andropogon furcatus[1]	2 or 3 stks., 2–6", poor.	Fair, 22", lvs. narrow.	Good, 20–24"	28", flr. stks. appearing.	Fine clump 18", lvs. slender and pale.	23–33", good, much attenuated.	Good, no flr. stks.
5. Bouteloua gracilis[1]	Starting feebly, 2–3", very narrow lvs.	Dead.					
6. Bouteloua racemosa[1]	Did not appear in 1921.						
7. Distichlis spicata[1]	Poor, 2–3"	Weak and few, 15"	15–19", poor, badly invaded.	Dead.			
8. Elymus canadensis[1]	Fine, 12"	Excellent, 40"	Headed at 4.5 ft.	Heads at 4.5 ft.	Exc. 36"	Exc., many heads at 50".	Exc.
10. Panicum virgatum[1]	2 or 3 stks. 12", normal.	Fine, 36"	Good, 3.5–4 ft. flowering.	4.5 ft. normal	Good, 22"	Good, spreading, many flr. stks. half out at 35".	Flr. stks. to 60", good.
11. Poa pratensis[1]	Good, 4–6"	Nearly normal	Normal, 12"	Normal	Merged into native sod.	Marker removed.	
12. Spartina cynosuroides[1]	Normal, 8"	Good, 36"	3–3.5 ft. good	4–4.5 ft. flowers	Normal 30"	Good	Normal 50", no flr. stks.

Species.	1923.	
	June 7.	Aug. 25.
7. Distichlis spicata	A few spears only, 9"	Dead.
8. Elymus canadensis	Fine, 18"	Flowering abundantly at 31"–42".
10. Panicum virgatum	Sparse but good	Not flowering.
12. Spartina cynosuroides	About 24", good	Normal.
2. Andropogon furcatus[1]	Not abund., 14"	Fair, 23".
8. Elymus canadensis.[1]	Fine, 24"	Flr. stks. abund. at 56", heads large.
10. Panicum virgatum.[1]	Normal	Excel.
12. Spartina cynosuroides[1]	Good	Normal.

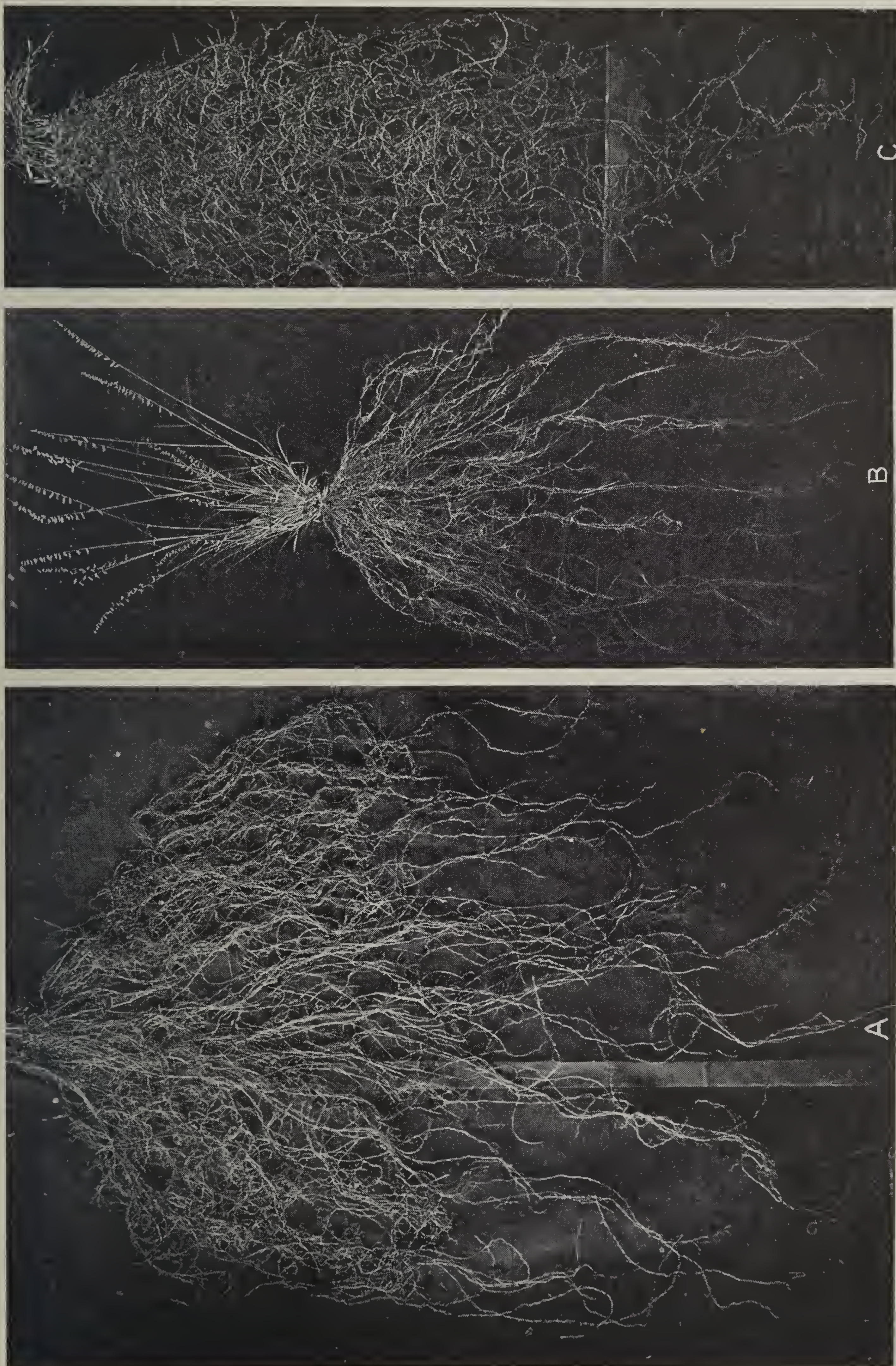
[1]Transplanted into the Poa zone.

A.—Detail of high prairie, showing the luxuriant estival society and amount of forage produced in June.
B.—General view of high prairie at Lincoln, Nebraska.

A.—Mixed-prairie station at Phillipsburg, Kansas.
B.—Corner of short-grass plains station at Burlington, Colorado.



Root system of year-old *Andropogon scoparius* (A) and *Stipa viridula* (B), upland cultivated soil at Lincoln; maximum penetration 4 and 2.7 feet respectively.

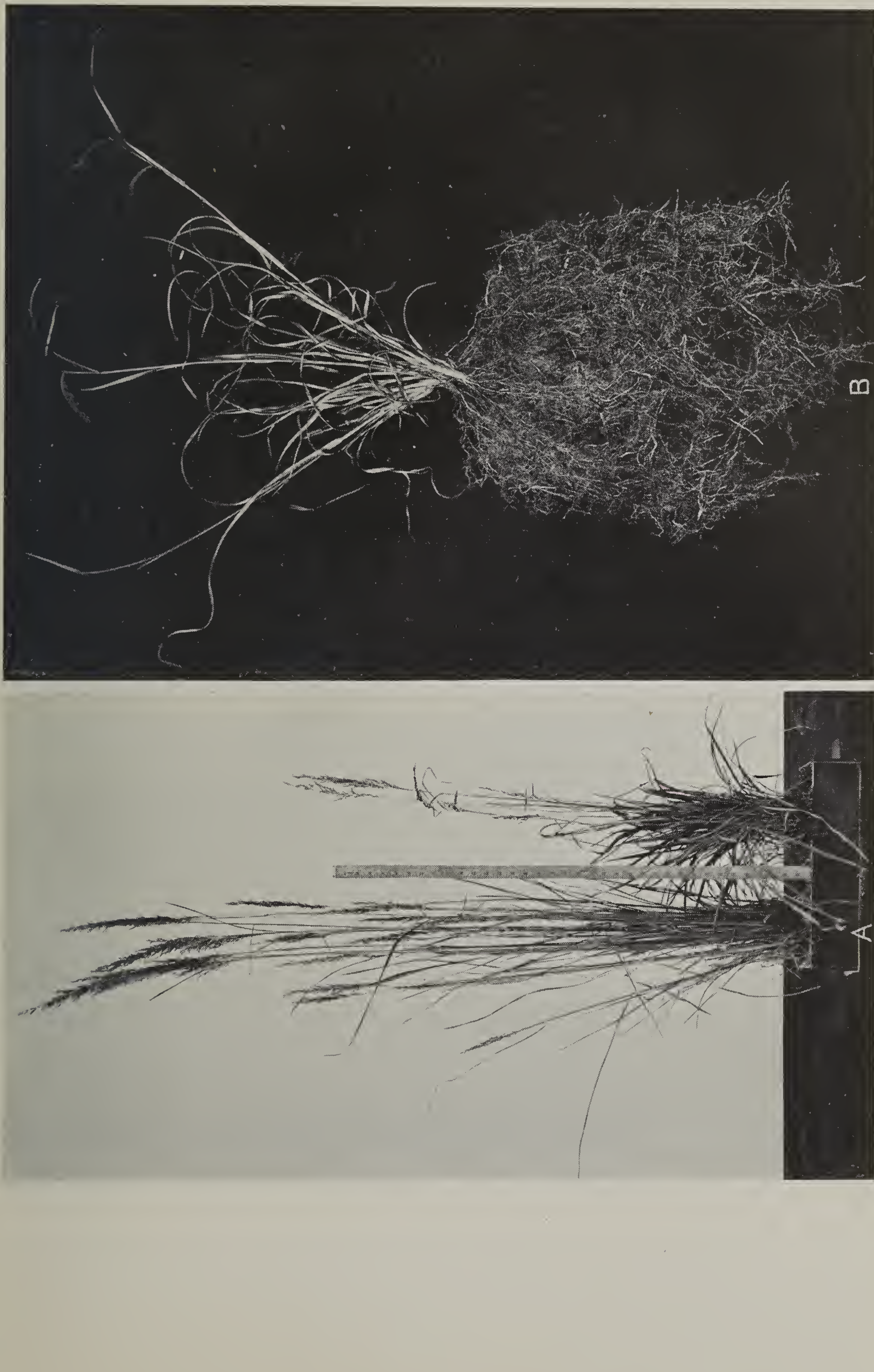


Year-old *Elymus canadensis* (A), *Bouteloua racemosa* (B), and *Andropogon nutans* (C); maximum penetration about 3, 3, and 4 feet respectively.

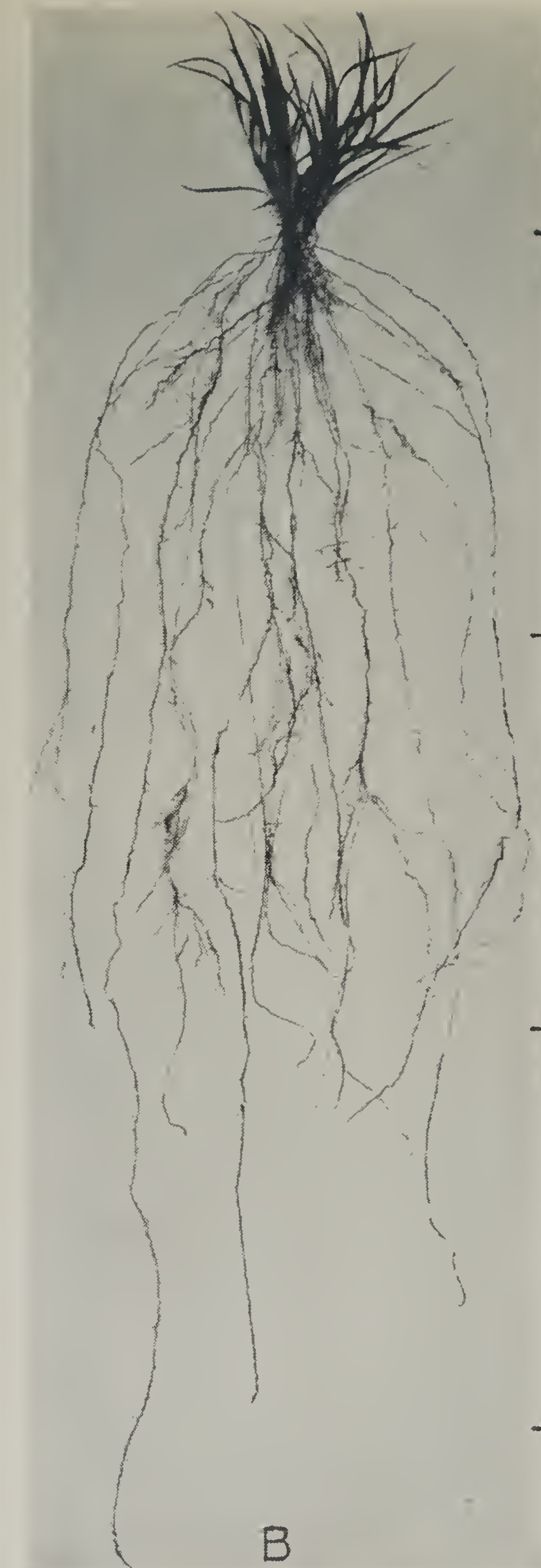
A.—Gravel-knoll station, Lincoln.
B.—Low-prairie station, Lincoln, showing transplanted sods.

A.—Low-prairie station in September showing height of subclimax dominants.
B.—Salt-flat station, Lincoln; the chief grass is *Distichlis spicata*.

A.—View of sod transplants in swamp at Lincoln, showing water standing on surface.
B.—Subclimax prairie at Nebraska City, showing rank growth of *Stipa spartea* and *Ceanothus ovatus* held in check by mowing.



A.—A single season's growth of *Andropogon nutans* from block of sod (left) and from seed (right) on low prairie at Lincoln.
B.—Year-old *Bouteloua hirsuta* grown on high prairie at Lincoln.



A.—Year-old seedlings of *Andropogon scoparius* (right), *A. nutans* (center), and *A. furcatus* (left) grown on high prairie; plants about 6 to 8 inches tall.

B.—Root system of year-old *Andropogon furcatus* from cultivated lowland, Lincoln; scale in feet.

A.—*Bulbilis dactyloides* sod in high prairie.
B.—*Andropogon nutans* in September of first season, showing marked growth without competition.

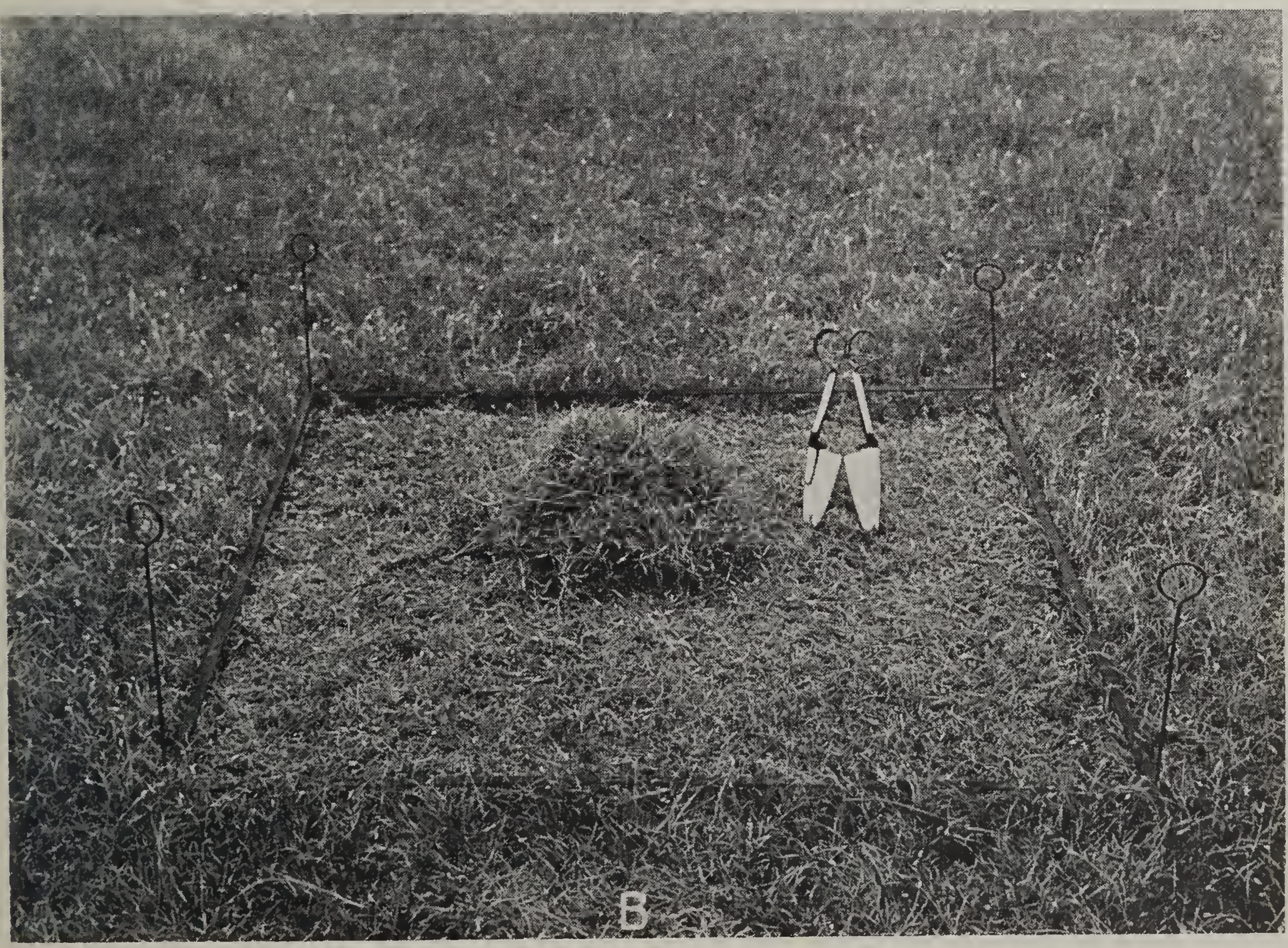
A.—*Calamovilfa longifolia* in September of first season, grown in rich silt-loam.
B.—*Bouteloua gracilis* one year old, grown in cultivated soil.

Roots of year-old *Muhlenbergia pungens* (A) and *Calamovilfa longifolia* (B) grown in rich silt-loam; depths of penetration 2.5 and 6 feet respectively. (C) *Andropogon halli* at end of first year in silt-loam.

Andropogon nutans planted in denuded quadrats at Nebraska City (A) in 1922, (B) in 1920. Photographed June 3, 1922.

A.—Two-year old *Liatris punctata* (left) and *L. scariosa* (right) grown without competition in cultivated soil; the largest plant had 107 heads.

B.—Year-old *Desmodium canescens* and (C) two-year-old *Onagra biennis* grown in cultivated soil at Lincoln; maximum heights 5 and 7 feet respectively.



A.—Sod-cores and details of installation, Burlington.
B.—Clip-quadrat in *Bulbilis-Bouteloua* short-grass, Burlington.